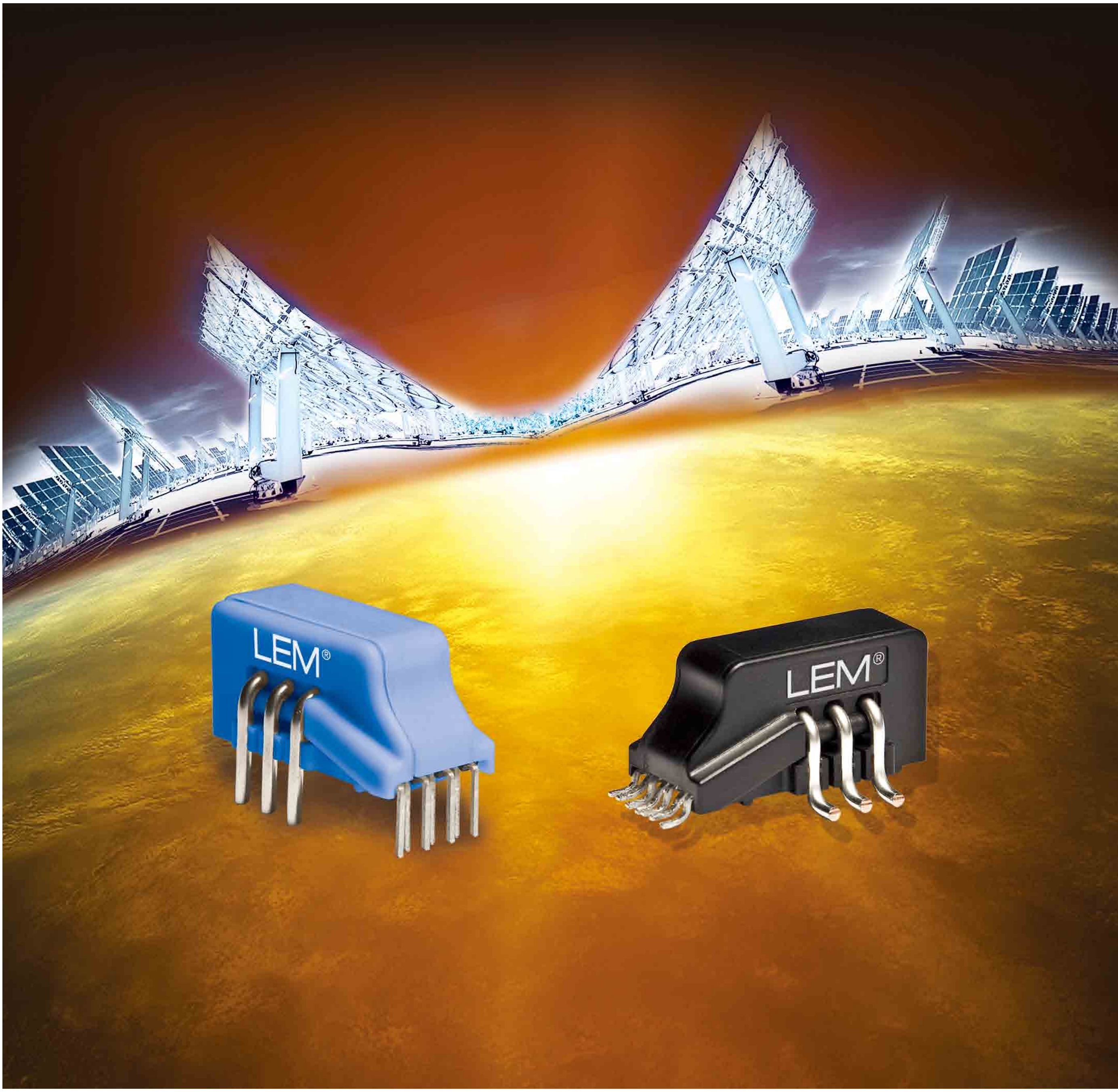
PSD EUROPE

December 2012

Power Systems Design: Empowering Global Innovation



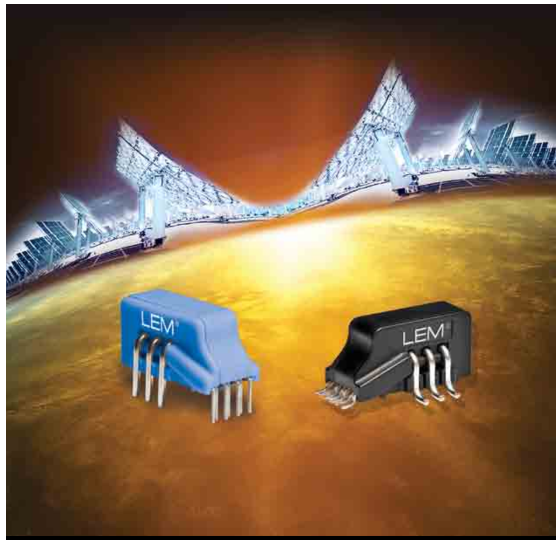
Special Report: Wind and Solar Power (pg37)

PSD EUROPE

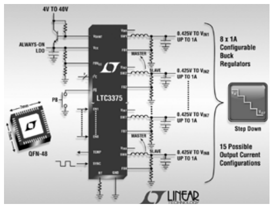
Power Systems Design: Empowering Global Innovation

WWW.POWERSYSTEMSDESIGN.COM

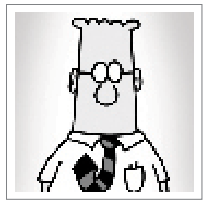
Visit us online for exclusive content; Industry News, Products, Reviews, and full PSD archives and back issues



COVER STORY
Control and protection rests on measurement precision (pg 15)



Highlighted Products News, Industry News and more web-only content, to:
www.powersystemsdesign.com



PSD EUROPE

AGS Media Group
146 Charles Street
Annapolis, MD 21401 USATel: +410.295.0177
Fax: +510.217.3608
www.powersystemsdesign.com

Editor-in-Chief
Joshua Israelsohn, Editor-in-Chief, Power Systems Design
joshua@powersystemsdesign.com

Contributing Editors
Gail Purvis, European Editor, Power Systems Design
Gail.Purvis@powersystemsdesign.com

Liu Hong, Editor-in-Chief, Power Systems Design China
powersdc@126.com

Ash Sharma, IMS Research
Ash.sharma@imsresearch.com

Dr. Ray Ridley, Ridley *Engineering*
RRidley@ridleyengineerng.com

David Morrison, How2Power
david@how2power.com

Publishing Director
Jim Graham
jim.graham@powersystemsdesign.com

Publisher
Julia Stocks
Julia.stocks@powersystemsdesign.com

Circulation Management
Kathryn Phillips
kathryn.phillips@powersystemsdesign.com

Magazine Design
Louis C. Geiger
louis@agencyofrecord.com

Production Manager
Chris Corneal
chris.corneal@powersystemsdesign.com

Registration of copyright: January 2004
ISSN number: 1613-6365

Volume 9, Issue 10

Nano adopts the ancient skill of mending

Renewable-energy efficiencies, certainly in the photovoltaic sector, have a long and steady history as the PV cell has been continuously improved for space use, picking out better- to best-suited raw materials. That classic in technical graphics must be that of NREL showing Best Research Cell Efficiencies, and that tracked advances in multijunction concentrators, Crystal-line Si, TFT (thin-film technologies), and emerging organic cells from 1975 to 2000.

Currently one of Europe's more intriguing projects underway has the UK's NPL (National Physical Laboratory) working in it on a European project to find a way to overcome the damage caused by nano defects on flexible electronics. It's a €7.25m project, with the University of Huddersfield leading the field and involves measurements of surface topography and defect geometry, using optical super-resolution techniques.

NPL of course has its own design instruments, such as the Areal (for 3-D surface parameters), MAFM (metrological atomic-force microscope), and NanoSurf IV, providing high accuracy and direct traceability to the metre. In addition to these, it has an extensive range of commercial instruments, including a stylus instrument and non-contact instruments—scanning white light interferometer, variable focus and confocal microscopy—also available.

Flexible electronics for solar modules (and digital display) are highly vulnerable to defects that range from fine dust particle to pin holes. The project's aim is to develop imaging, detection, and correction technologies for use in high speed manufacturing of these products.

There are two pilot lines in the current mend project. One is being developed for the manufacturing lines of polymer-coated-paper packaging at Finland's Stora Enso, to extend the shelf life of carton drinks, and use less material. The other is for the manufacturing lines of the Swiss flexible solar-cell start up, FLISOM.

Nanomend will be used to detect and correct defects within various layers of the solar module to increase its efficiency, lifespan, and economic viability for consumers. FLISOM has already worked with the scientific sector gaining help from the Swiss EMPA team, who made significant progress in low-temperature growth of CIGS layers, yielding more flexible CIGS cells with record values rising from 14.1% in 2005 to the *high score* of 18.7% for any type of flexible solar cell grown on polymer or metal foil.

It was achieved by reduction in recombination losses, improving the structural properties of the CIGS layer and the proprietary low-temperature deposition process for growing the layers, as well as in situ doping with Na (sodium) during the final stage. With these results, polymer films have for the first time proven to be superior to metal foils as the carrier substrate for highest efficiency. "Results clearly show the advantages of the low-temperature CIGS deposition process for achieving highest efficiency flexible solar cells on polymer as well as metal foils", says PV and TFT expert Professor Ayodhya Tiwari.

After mending, one suspects, the future for smart materials at least will have to be that layer deeper, as self-heal or auto-mend become obligatory.

Gail Purvis,

European Editor, Power Systems Design
Gail.Purvis@powersystemsdesign.com

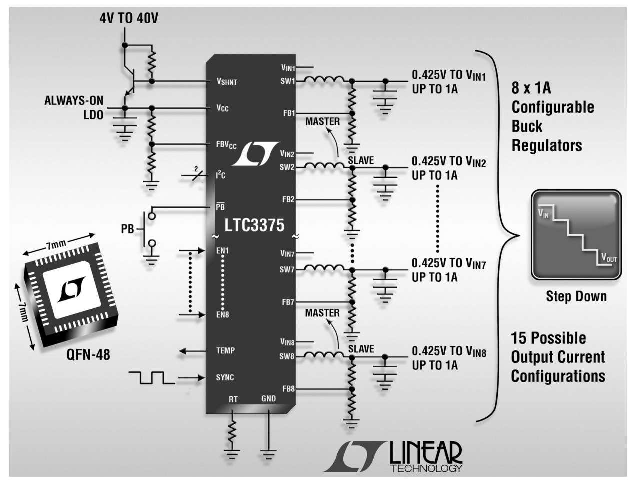
Octal configurable 1-A buck DC-DCs for multi-rail systems

Linear Technology's LTC3375 is a highly integrated general-purpose power management IC for systems requiring multiple low-voltage power supplies. The device features eight independent 1-A channels with I²C control, flexible sequencing, and fault monitoring in a compact QFN package.

Each channel is a high efficiency synchronous step-down regulator with its own independent 2.25 to 5.5-V input supply and an output voltage range of 0.425 V to V_{IN}. In addition, the LTC3375's buck DC-DCs may be connected in parallel to achieve higher output currents up to 4 A per output with a single shared inductor. Up to four adjacent regulators can combine, resulting in 15 different possible output configurations. All of the switching regulators are internally compensated and need only external feedback resistors to set the default output voltage.

The LTC3375's pushbutton ON-OFF-RESET control, power-on reset, and watchdog timer provide flexible and reliable power-up sequencing and system monitoring. All buck output voltages are adjustable via I²C for margining or power optimization.

The LTC3375 features a programmable and synchronizable 1- to 3-MHz oscillator with a 2-MHz default switching frequency. The device also contains a high-voltage input shunt-regulator controller, and quiescent current is only 11 µA with all DC-DCs off. It is well suited for a wide variety of multichannel applications including industrial, automotive, and communications systems.



High-power octal 8 x 1-A buck DC-DC

Adjacent buck regulators can combine in a master-slave configuration by connecting their V_{IN} and SW pins together, and connecting the slave bucks' FB pin(s) to the input supply. The switching regulators offer two operating modes: Burst Mode operation (power-up default mode) for higher efficiency at light loads, and forced continuous PWM mode for lower noise at light loads. The I²C interface can select mode of operation, phasing, feedback regulation voltage, and switch slew rate. The bucks have forward and reverse current limiting, soft-start to limit inrush current during start-up, short-circuit protection, and slew rate control for lower radiated EMI. Other features include a die temperature monitor output (readable via I²C or the analog voltage on the TEMP pin), which indicates internal die temperature, and an OT (over-temperature) warning function, indicating high die temperature.

The LTC3375 is available from stock in a thermally enhanced, low-profile (0.75-mm) 48-pin 7- x 7-mm exposed pad QFN package. E and I grades are specified over an operating junction temperature range of €40 to +125 °C, and the H grade features operation from €40 to +150 °C. 1000-piece pricing starts at $5.45 each for the E grade.

www.linear.com

ARM throws weight behind Weightless

Reported by Gail Purvis, Europe Editor, Power Systems Design

At the beginning of November, ARM made two moves that confirm it not only as a power architect, with a strong community bent, but also as a strategic power team player. With Cable & Wireless Worldwide, CSR, and Neul, it signed up as the promotor of a SIG (special interest group) to accelerate adoption of the Weightless standard, and it announced it is a major participator in the MIPS portfolio, contributing $167.5 million as its share.

The Weightless group comprises 50 high-technology companies focused on the development of a standard designed specifically for short to mid-range M2M (machine-to-machine) communication. The group will deliver a royalty-free open standard and on is track for completion in early 2013.

The formation of a SIG means impetus and better focus on the common set of standards delivering the key requirements, not just for M2M communications, but also to enable the IoT (Internet of Things) technology. The goals include a chipset cost of under $2, a range of up to 10 km, and a battery life of 10 years.

ARM CTO Mike Muller said, "The Internet of Things requires new thinking about technology. As data levels soar across the world, new ways need to be found to ensure wireless communications can be seamless."

"This includes the next wave of connectivity across smart grids, enhanced healthcare, smart cities, asset tracking sensor, and future applications as yet unimagined. With common standards, we can all benefit for intelligence embedded and connected everywhere, so the ARM team is excited about the huge potential this standard will unlock."

As a lead member of Bridge Crossing LLC, a consortium of major technology companies affiliated with Allied Security Trust, ARM is in the agreement with MIPS to obtain the rights to its patent portfolio. The MIPS portfolio includes 580 patents and patent applications covering microprocessor and SoC design and other related technology fields. The consortium is to pay $350 million in cash to acquire rights to the portfolio, of which ARM will contribute its $167.5 million from cash reserves.

Upon the transaction's completion, the portfolio will support continued innovation in SoC design and, equally important, will also remove any potential litigation risk presented by the MIPS patent portfolio with respect to the consortium members. The consortium will also make licenses to the patent portfolio available to other companies not within the consortium.

"ARM is a leading participant in this consortium which presents an opportunity for companies to neutralise any potential infringement risk from these patents in the further development of advanced embedded technology," said ARM CEO Warren East. "Litigation is expensive and time-consuming and, in this case, a collective approach with other major industry players was the best way to remove that risk."

www.arm.com

Intense challenges for PV-inverter suppliers in 2013

By: Ash Sharma, Director, IHS Solar and IHS IMS Research

2012 was tough for most suppliers of solar PV products. Despite growing market volumes, a sharp demand slowdown led to oversupply and price competition. Many companies with weak financial positions failed, whilst others exited the market before conditions worsened further—a contrast to 2011 when the $100 billion industry was growing at a triple-digit rate.

IMS Research forecasts 2013 to be another challenging year for PV component suppliers. Whilst panel suppliers have taken the brunt of the price erosion, now inverter manufacturers face flat revenue growth globally and a shift away from traditional markets leading to a reshaping of the supplier base. Top-ten inverter manufacturers are likely to suffer because of falling inverter prices. Markets such as Japan, China, India, and the U.S. will also be difficult to penetrate and may not compensate for decreases in their core markets, Germany and Italy. Recent profit warnings, and Chapter-11 filings by SMA and Satcon, highlight the challenging conditions all PV inverter manufacturers face, which may not improve until 2014.

IMS Research forecasts double-digit growth of PV installations with 35 GW predicted to install in 2013. However, inverter revenues will remain flat as prices decline in a competitive market as manufacturers attempt to break into new geographies and gain share. A major geographic demand shift, coupled with price pressure will challenge leading PV inverter suppliers in 2013.

Although the U.S. and key Asian countries will make up for the shortfall left by shrinking markets in Italy and Germany, these markets may not be easily accessible to many leading inverter suppliers and market penetration will be challenging. Some challenges that inverter manufacturers will face in 2013 will be certification standards, lower cost bases, local-manufacturing requirements, and competition from local suppliers. As some of the Asian countries have lower price points, one hurdle for inverter makers in 2013 is that they won't be able to subsidize Asia operations by their profitable European business.

As FiT cuts have occurred in mature markets such as Germany and Italy, manufacturers are increasingly looking to the growth markets of U.S. and Asia. Manufacturers that can penetrate these markets will reap future benefits as the market develops. Longer-term horizons and sound strategic decisions will be needed in future years as the market fragments due to its diverse geography, as more PV markets develop, including South Africa and South America.

For manufacturers that withstand the challenges of 2013 and penetrate the emerging markets, future years should return to double digit growth as the PV market matures. Key inverter markets, however, won't be centered in Europe but spread over several continents. IMS Research forecasts that Europe accounted 54% of global shipments in 2012, but this will fall to 40% by 2014. As a result, IMS Research predicts that the top-ten manufacturers in 2014 will be different to those of today, with many more Chinese and Japanese companies.

www.ihs.com

Input impedance measurements and filter interactions: Part III

By: Dr. Ray Ridley, President, Ridley Engineering

In this article, Dr. Ridley continues the discussion of power supplies with input filters. He shows how the presence of a poorly-designed filter has a drastic effect on the loop gain of a voltage-mode controlled system. He also shows that the loop gain of a current-mode system can be a poor indicator of stability when an input filter is connected to the system.

Impedance Interactions

As discussed in the previous articles of this series [1], an input impedance measurement gives information about the characteristics of the power supply's input terminals. We use this information in conjunction with measurements of the output impedance of the input filter to assess whether a system interaction is likely to occur. This is important since it can lead to instability of the power supply.

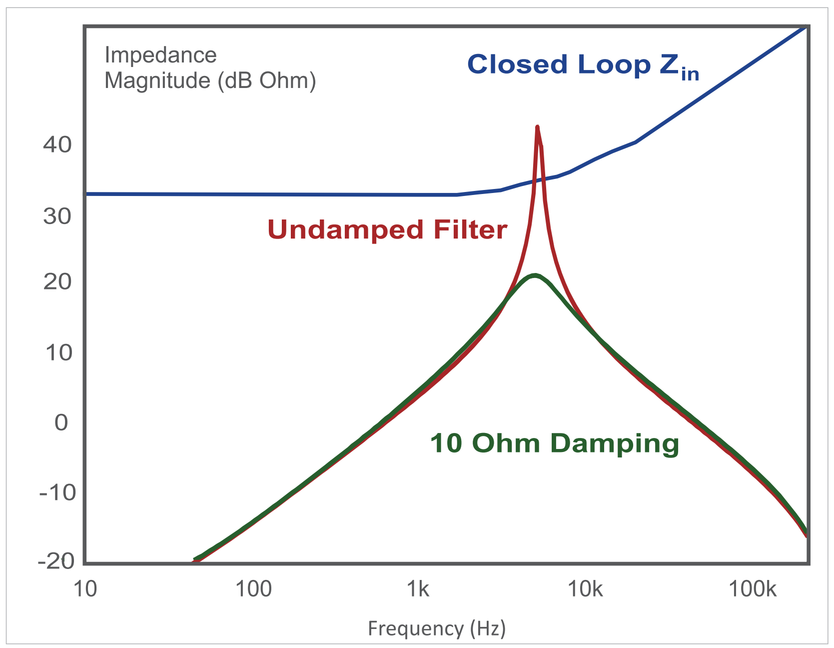


Figure 2: Comparison of measurements of power supply input impedance and input filter output impedance. With an undamped filter, the output impedance exceeds the input impedance of the power supply.

Figure 1 shows a power supply with an input filter. As shown in the last article of this series [1] a damping network is often needed to control the peaking of the output impedance of the filter.

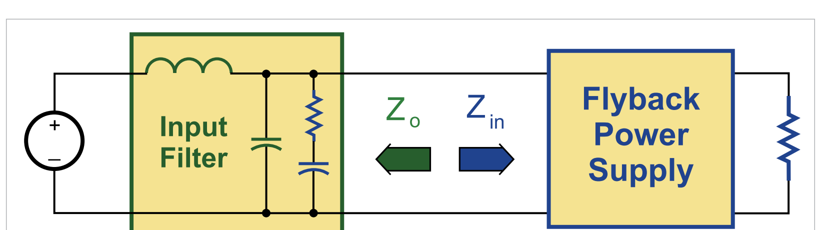


Figure 1: Power supply with input filter module. A damping network is used to control the output impedance peaking.

Middlebrook's important work on input filter interactions showed that if the output impedance of the input filter is always less than the input impedance of the power stage, there would not be any instability caused by the presence of the input filter. This is a very important result since it allows us to analyze the power stage completely separately from the input filter. Switching power supplies are difficult enough to analyze and control, and Middlebrook recognized that engineers really don't want to extend their analysis further to include multiple reactive components of the input filter. He wanted to keep the math simple. **Figure 2** shows measurements of a power supply input impedance, compared with the output impedance of two different filter designs.

The first output impedance, shown in red, is for an undamped filter. It can be seen that the output impedance is higher than the input impedance of the power supply. The second curve shows the output impedance for the same filter elements with a 10 ohm resistor in series with a capacitor connected across the output of the filter. For the damped filter, there is a good separation of the output impedance of the filter and the input impedance of the power supply, which is the desired design result.

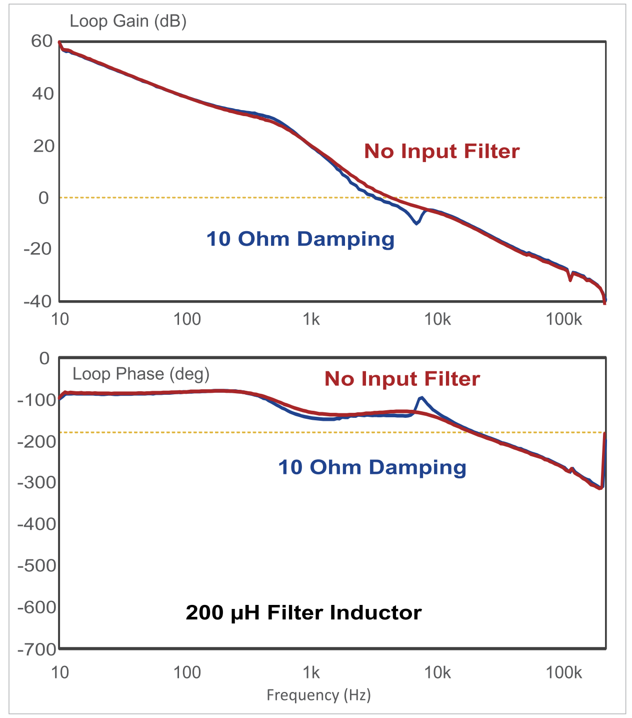


Figure 4: Voltage-mode control loop gain with a properly-damped input filter.

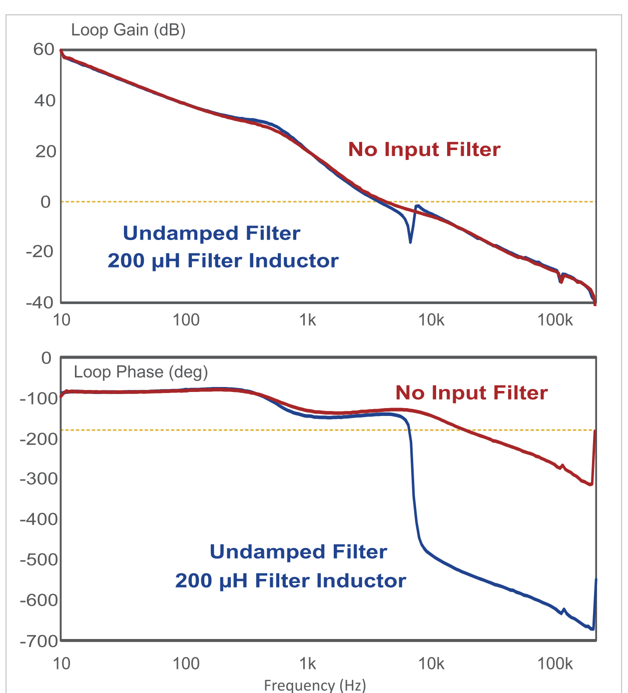


Figure 3: Voltage-mode control loop gain with an undamped input filter.

Voltage-Mode Feedback Loop Gain Measurements

It is instructive to look at the loop gains of the power supply to see how the presence of the input filter affects that measurement. **Figure 3** shows the voltage-mode control loop for the system of Figure 1, both with and without a filter.

The red curve of Figure 3 shows loop gain without a filter added. The crossover is at around 6 kHz, and there is a phase margin of about 50 degrees.

Adding the undamped filter has a dramatic effect on the voltage-mode loop gain. There is a notch in the gain, and then the high frequency part of the loop gain follows the same curve as the system without a filter. However, the phase at the notch frequency drops dramatically – ending up with an additional phase delay of 360 degrees! This large drop in phase is due to an additional pair of poles caused by the input filter, and a pair of complex RHP zeros.

Trying to analyze this complete system with four poles, three zeros, and three additional control states is not something that you really want to do. Hence the Middlebrook criteria – you can avoid this unpleasant math by just looking at the impedances and making sure they are well separated.

Figure 4 shows the loop gain of the voltage-mode system with a properly damped input filter. In this case, there is no overlap of impedances, and the effect on the loop gain is much less dramatic. Although there is still a small notch in the gain, the phase does not exhibit the same dramatic drop as for the system with the undamped filter.

Clearly, from looking at Figures 3 and 4, we can assess the impact of the input filter on the overall power system.

Current-Mode Feedback Loop Gain Measurements

The situation is not so straightforward when we look at the loop gain of a current-mode controlled system. The red curve of **Figure 5** shows a well-designed feedback

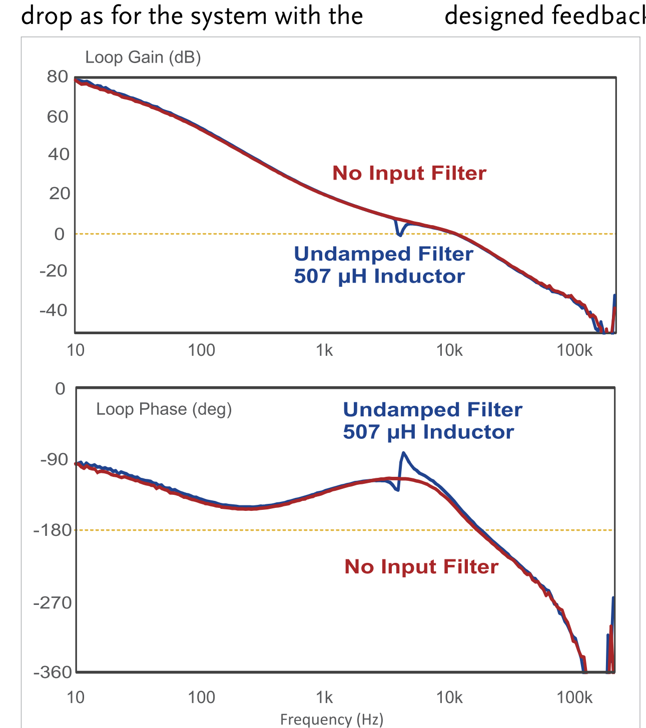


Figure 5: Current-mode control loop gains without a filter and with an undamped input filter. The current-mode loop gain is not a good indicator of the stability of the system with the input filter.

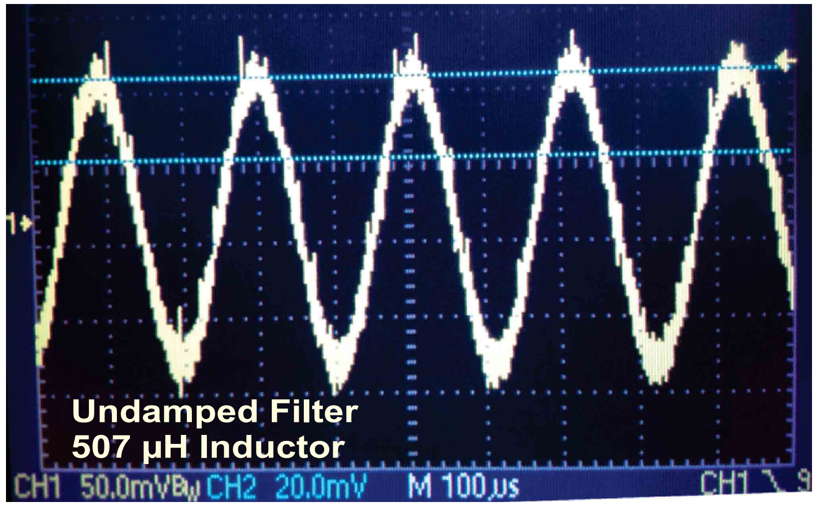


Figure 6: Despite the apparently-stable loop gain, oscillations can be seen in the current-mode system

loop with a crossover frequency of close to 10 kHz, and plenty of phase margin. When the undamped input filter is added, there is not much of a change to the loop gain.

The loop gain of Figure 5 predicts that the system is stable when in fact there is oscillation in the system. **Figure 6** shows the voltage waveform at the output of the input filter (ie the input of the power stage). There is sustained ringing at this node of the circuit, but it cannot be observed at the output of the power supply at all.

In control terms, this is what we call an unobservable system. You cannot see disturbances on the input rail when you look at the output voltage. Oscillations at the input bus are immediately adjusted for by the current-mode modulator, and the output remains regulated.

This is not a good way to design your power system. It is crucial that input impedance and filter output impedance measurements are measured to ensure that there will not be any instability. Looking at the loop gain is not sufficient to guarantee that the system will be stable.

This is something of an alarming situation. Most switching power supplies are designed with current-mode control. Most switching power supplies are also designed with input filters. Most designers do NOT make measurements of input impedance and filter output impedance, leaving themselves at risk of instability even if they are making loop gain measurements.

The reason this does not happen too frequently is that filters have been designed in the past with large electrolytic capacitors. The characteristic output impedance of the input filters with large capacitors is inherently low, greatly reducing the risk of input impedance interactions. For modern capacitor technologies, a small-value MLC capacitor can carry all of the necessary switching current, and the input filter impedance can be much higher.

Summary

This article discusses how input filter impedance interactions have a dramatic effect on the loop gain of a voltage-mode controlled system, introducing an additional 360 degrees phase delay in the loop if the filter is poorly designed. Proper damping of the input filter is needed to make sure the system is stable.

For current-mode control, it has been shown that filter interactions are far more difficult to detect with the loop gain measurement, and a system can have an apparently good loop gain while exhibiting oscillations. It is very important to make sure loop gains and impedances are measured to ensure a stable power system.

References

1. Ridley Engineering Design Center, www.ridleyengineering.com/index.php/design-center.html, Article [59-61] "Input Impedance Measurements and Filter Interactions."

www.ridleyengineering.com

Control and protection rests on measurement precision

Galvanically isolated current transducers address numerous measurement challenges

By: Stéphane Rollier, Product and MarCom Manager, and Bernard Richard, Business Development Manager, LEM

Designers of solar power—photo-voltaic or PV—generating systems face some of the same problems as their counterparts in any other power-related technology: the need to constantly improve performance, reliability, longevity, and—above all—efficiency. As with any engineering endeavour, improved performance requires with higher-quality and more-accurate measurements.

Of the installations worldwide that are actively feeding power into national and trans-national power grids, around 40% of the total installed capacity is located in Europe and, of that, the largest national installed base is in Germany. In 2011, Germany's cumulative PV generating capacity was just under 25 GW, and in that year its PV power stations generated some 18 TWh for the German grid.

The rapid ramp-up in PV installations can be judged from historical trends: Although connection of solar generating capacity to the grid dates back to the early 1990s, the first GW figure in Germany was reached only in 2004. However, installed capacity grew by 7.5 *GW* from 2010 to 2011 alone. Other countries have seen PV installations grow at a similar rate.

This almost-exponential growth has been partly driven by generous feed-in tariffs available to those who contracted to provide solar power to the grid, early in the adoption of the technology. In many territories, those initial attractive terms are no longer available, increasing the pressure on system designers to deliver more and more power to the grid from each unit of incident solar radiation and, as systems become more powerful, to do so safely.

PV-system efficiency comes from a number of sources: Semiconductor technologists strive to increase further the conversion efficiency of the basic silicon cells, but much attention focuses on inverter architecture and control. Maximising inverter performance depends on accurate measurements of current and voltage and precision measurements of basic parameters underpin several functions of the solar inverter. The most obvious is fiscal: metering exactly how much billable energy an installation has generated and transferred to the grid in a given period. Next, there is the need to maximise power conversion and, finally, there is a need to monitor possible leakage-current paths to ensure that the solar arrays and their inverters are safe for those working on and around them.

Isolated measurement technology

At all points in the power conversion chain, it is advantageous to carry out current measurements with non-intrusive technologies, that is, with sensors that do not directly connect into the circuit subject to measurement. This provides galvanic isolation from the—possibly very high—potentials of the power-generation path and eliminates I^2R losses associated with inserting resistive sensing elements into power paths.

Key to conversion efficiency is maintaining the MPPT (maximum peak power transfer) point. Power output from the PV array is the V-I product of the terminal voltage and the DC current delivered. As with any DC supply that has a source impedance, the voltage drops as the current increases. In solar cells, the relationship is not linear, and varies with the level of light energy reaching cells. The algorithms that control the inverter must constantly adjust the operating point to maintain operation at MPPT. The DC values that determine MPPT change relatively slowly, and moderate measurement precision is sufficient to determine the optimum operating point. Therefore, systems can make these DC current measurements with current transducers that use open- or closed-loop Hall-effect technology.

Various PV installations use a number of inverter designs. Commercial and large PV arrays on industrial or agricultural sites usually series-connect solar panels to deliver a high DC voltage to a high-power inverter with a single feed to the grid. In smaller, typically domestic or commercial installations, work continues to optimise the micro-inverter concept in which conversion to mains voltage is done at each panel. Today micro-inverters are not cost-effective in comparison with traditional technology. Monitoring the aggregate AC fed to the grid in this arrangement presents a separate measurement challenge.

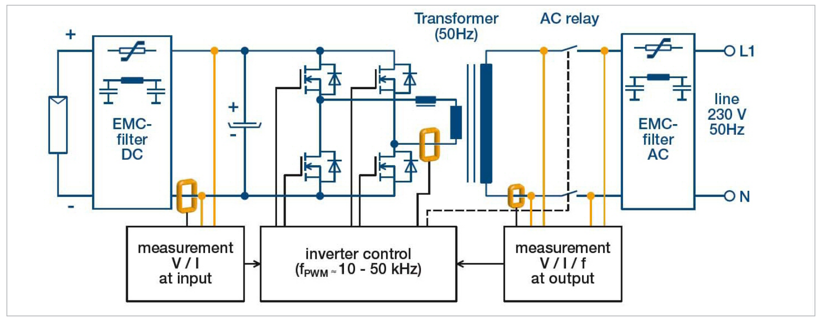


Figure 1a

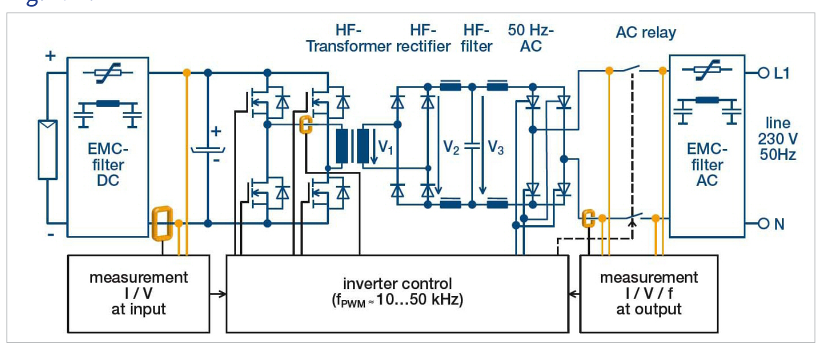


Figure 1b

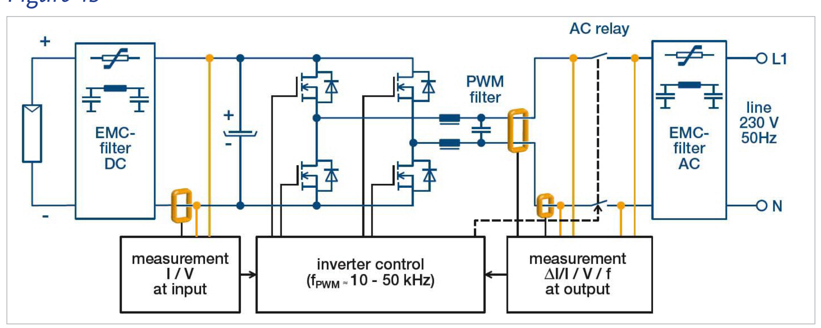


Figure 1c

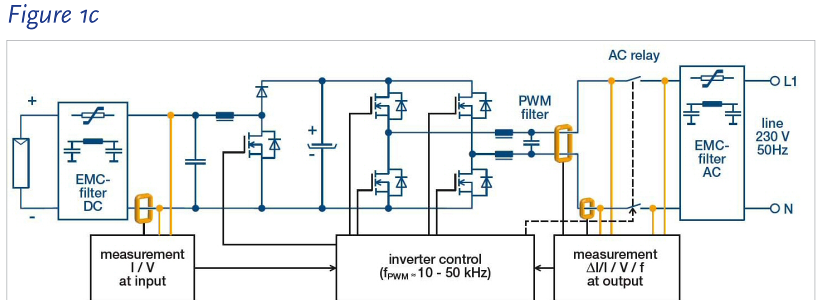


Figure 1d

Figure 1: Four main inverter designs commonly encountered with their current measurements: Inverter with low-frequency transformer (a), with high-frequency transformer (b), transformerless without DC chopper (c), and transformerless with DC chopper (d).

PV installations can make the connection of the solar array through an inverter to the grid either by using a transformer or directly without a transformer. Transformerless installations have no galvanic isolation, with a consequent risk of leakage to earth: Both configurations may also operate with or without energy storage in a battery.

Four main inverter designs are commonly encountered. Two designs use a transformer (at low or high frequency) and two designs are transformerless—with or without a DC chopper or step-up converter. The low-frequency transformer design switches the DC from the PV array at the 50-Hz mains frequency and the transformer (depending on the DC potential available) steps it up to the grid voltage. This provides isolation, eliminates the possibility of DC injection into the grid but implies a large transformer, and is not maximally efficient. This architecture requires measurements at the output of the solar panel and at the AC output to the grid. An alternative is to switch the DC at a higher frequency—tens of kHz—into a step-up transformer, rectify that to an intermediate DC at grid potential, and then use a further switch to generate AC synchronised to the grid. This arrangement is more complex and, depending on the accuracy of the output switch, may inject DC into the grid. Transformerless architectures switch a DC potential, either direct from the PV array or via a step-up *chopper* stage into synchronised AC that feeds directly (via a filter) to the grid. As there is no galvanic isolation between PV panel and grid, fault and leakage paths can potentially expose personnel working on and around the panels to dangerous or lethal voltages.

All of these inverter configurations require current and voltage measurements both at the output of the PV array and at the AC output of the inverter, both for control of the inverter and to detect fault conditions (**figure 1**). Again, open- and closed-loop Hall-effect transducers can provide the necessary accuracy, with fast-response modes providing short-circuit protection.

Addressing exactly this class of application, LEM recently introduced the HO series of open-loop Hall-effect-based transducers. HO series transducers measure up to 25 A—for DC, AC, or pulsed currents—with accuracy as good as 1% at +25 °C. They provide designers with great flexibility as the devices are highly programmable and configurable so that one part can perform multiple roles. A separate over-current-detection function also adds an extra level of safety and

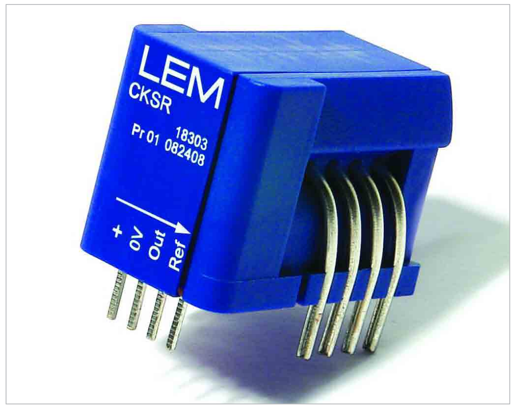


Figure 2: CAS/CASR/CKSR current transducer series use closed-loop fluxgate technology.

circuit protection.

DC-to-grid and leakage detection
In transformerless designs and in high-frequency transformer configurations, the DC current injected into the grid must be limited to a maximum value of between 10 mA and 1 A, according to different standards that apply in different countries. Relevant standards include IEC 61727, IEEE 1547, UL 1741, VDE 0126-1, and IEC 62109-2. This necessitates use of transducers with very high accuracy and very low offset and gain drifts. The closed-loop fluxgate transducer exhibits these properties (**figure 2**).

Transformerless inverters without galvanic isolation have a potential for leakage currents to occur and it is a requirement to monitor leakage current. Any AC 50- or 60-Hz leakage currents will be small, and must be less than 300 mA, depending on the capacitance due to the solar panel-roof configuration. The system measures the leakage as the residual component remaining from a differential measurement of currents in several conductors.

A person contacting a panel in a fault condition will generate a sudden current leakage variation, and the system must recognise this condition. In current transducer terms, this requires accuracy and, especially, low offset and gain drifts, to ensure resolution of these small measured currents. Physically, it means the ability to accommodate several conductors, to cater for a single- or three-phase system within the transducer aperture.

Figure 3: CTSR current transducer series, using closed-loop fluxgate technology, is available with an integrated test winding.

Similar demands apply to earth fault-current detection, arising from an insulation defect. The transducer used to measure the earth fault current must be able to measure AC and DC signals as the earth fault current could be AC or DC, depending where the fault (for example, a short circuit) occurs, and depending on whether the PV panel is grounded or not.

To achieve the targets in terms of accuracy with small currents, LEM applied its closed-loop fluxgate technology and created the LEM CTSR current transducer range (**figure 3**).

Closed-loop current transducers measure current over wide frequency ranges, including DC. They provide contact-free coupling to the current that needs to be measured in addition to safe galvanic isolation and high reliability. Their closed-loop operating principle, together with sophisticated internal signal processing, yields a transducer that achieves accurate measurement of very small residual DC or AC currents with very low offset and gain drifts over a wide operating temperature range from –40 to +105 °C. The residual-current capability measures the sum of all of the instantaneous currents flowing through the transducer aperture, in single- or three-phase configurations, with a very high overload potential up to 3300 A for a pulse duration of 100µsec, and with a rise time of 500 A/µsec. Conductors may be carrying primary currents of up to 30 A/wire, AC or DC.

www.lem.com

Active Network Management offered as grid panacea

Grid-management scheme helps integrate energy storage, demand-side management, renewable generators, and other resources.

By: Alan Gooding, Managing Director, Smarter Grid Solutions

The power industry faces some significant future challenges: to create a more visible and controllable electricity grid to deliver power more reliably, efficiently, and cost effectively and find smarter ways to accommodate higher volumes of renewables. In the UK, power companies must navigate a complex regulatory backdrop, which offers incentives for discrete smart-grid initiatives but will not introduce more long-term regulatory changes until 2015.

The result is that most power companies are likely to concentrate on project-based smart-grid initiatives in the shorter term, while preparing to incorporate smart-grid activity into their standard business procedures and planning in the future.

Smarter Grid Solutions Managing Director Alan Gooding observes "There is a lot of industry uncertainty regarding the uptake of low-carbon technologies and changes to demand patterns so our focus must be on answers that are not only valid today, but can evolve seamlessly and affordably to meet future customer requirements. Power companies recognize that an Active Network Management technology can help them use their existing assets more fully, create capacity for more affordable or timely connections, and manage the uncertainty and risks around when to upgrade parts of the network. It's vital that we and other smart-grid technology vendors continuously evaluate the industry's changing requirements to offer a flexible, scalable, and clearly-defined plan that can adapt to overcome the multiple and unforeseen obstacles power companies will face on their journey towards a fully deployed and integrated smart grid."

Power companies and utilities face demand for power that is changing in magnitude, timing, and type. They also confront higher operating costs. This makes price rises seem inevitable. Meanwhile, customers are increasingly sensitive to higher prices, so electricity regulators are using a combination of *carrot and stick* to convince power companies to find cost-effective ways to meet the demand for more power and new connections.

In the UK, the biggest carrot has been the Low-Carbon Networks Fund, established in 2010 by the energy regulator, Ofgem. Much of the existing UK smart-grid market has emerged in response to this and various other regulatory and Government incentives.

These incentives aim to encourage power companies and utilities to find innovative and cost-effective ways to accelerate the low-carbon economy by enabling high volumes of renewable and low-carbon technologies to connect to the electricity grid in ways that do not rely on expensive, carbon-intensive, and time-consuming grid upgrades.

The UK is currently among a

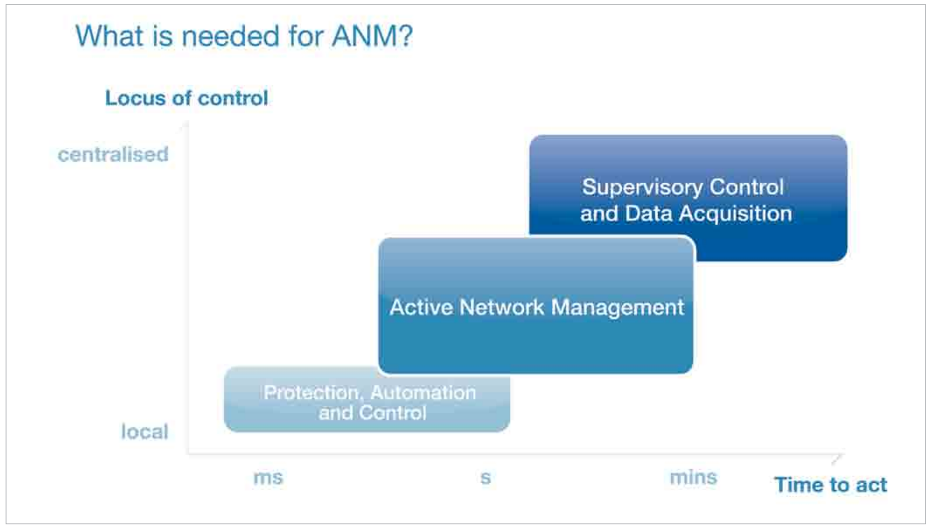


Figure 1: Active Network Management creates a new layer of grid management.

group of nations in smart-grid demonstration projects. This is a result not only of the new innovation and demonstration funding incentives, but also the abundant renewable energy sources available, and the impact of various European and UK energy policies. For example the UK Low Carbon Transition Plan sets out a goal of a 34% reduction in carbon emissions on 1990 levels by 2020 and an 80% reduction by 2050.

The regulatory framework for DNOs (distribution network operators) in the UK is also changing to give them clear incentives to start planning their long-term smart-grid strategies now. The existing DPCR5 (distribution price-control review) period ends in 2015. From then onwards, the UK energy regulator, Ofgem, is introducing a new price control framework, RIIO (revenue = incentives + innovation + outputs). The aim is that smart-grid design and delivery will no longer be restricted to specific innovation or demonstration projects but will become business as usual in the first RIIO period, which will last for eight years from 2015. Elsewhere in the world, regulators are keeping a close eye on these developments in the UK, as well as introducing their own new smart-grid funding, including the Smart Grid Fund in Ontario, Canada, the US stimulus package, and several initiatives across Europe.

It will take some time before smart grids become part of business as usual for all power companies and utilities since the substantial innovation incentives have yet to deliver fully the evidence required for full-scale smart-grid roll out. Nonetheless, a growing number of power companies are keen to explore and develop new smart-grid capabilities and business-as-usual opportunities. This will include finding means to recognize and exploit the opportunities from various grid-connected devices and system-operation participants, including customers, new grid technologies, ancillary service providers, and energy-market participants.

From the smart-grid technology vendor perspective, the challenge will be to provide flexible and extensible systems that can evolve to meet changing requirements as we move closer towards a low-carbon grid. These systems will need to flex to facilitate an incremental smart-grid rollout, or a top-down strategic investment approach, whichever proves to be the most cost-effective in a particular geographical or grid area.

Active Network Management

An Active Network Management scheme gives power companies and utilities more control over the way they deliver power and facilitate connections. It does this by providing greater visibility of the grid to tackle constraints of power flow, voltage, fault level, system stability, and system balancing (**figure 1**).

This allows power companies and utilities to make use of existing grid capacity to

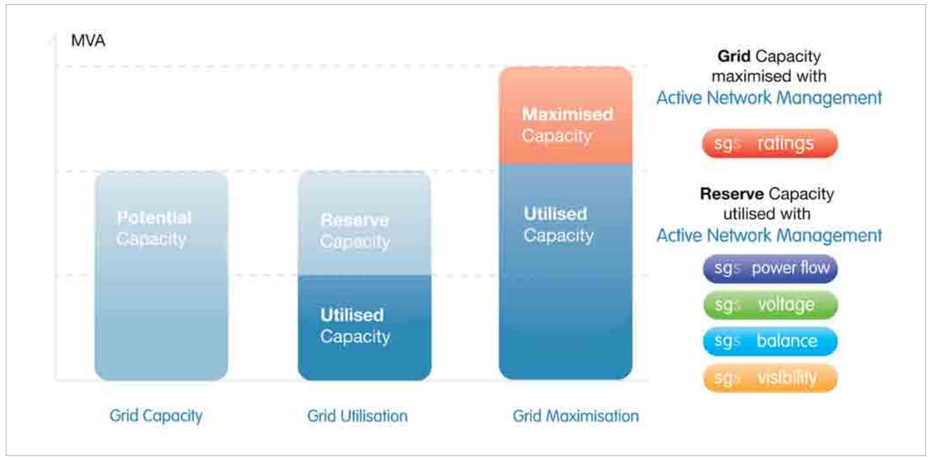


Figure 2: Active Network Management creates greater capacity in the existing grid.

integrate energy storage, demand-side management, renewable generators, and other controllable resources on the grid to produce a smarter and more efficient energy system, helping to reduce reliance on fossil-fuelled power stations and increase the amount of renewable generation connected to the electricity grid (**figure 2**).

Electricity regulators and utilities customers require more for less. They are calling for fewer outages and losses, together with lower costs for customers. For power companies and utilities, the only way to achieve this is to bring about a significant change in system design and operation.

A more affordable, visible, intelligent, and controllable electricity system via Active Network Management will enable:

- increased use of existing assets and avoidance or deferral of new grid infrastructure.
- new grid-management systems designed specifically to meet new challenges, leaving existing systems to continue to perform their existing role.
- continuous monitoring of the condition of system components to identify and
- repair faulty equipment to help prevent outages.
- monitoring and repairs in response to specific equipment conditions rather than on
- a scheduled, system-wide basis.
- real-time monitoring of power flows and voltages across the grid in order to
- minimise losses and enable more efficient generation.
- estimation of power system parameters and indications of the errors associated with estimates.
- better coordination of protective devices, so fewer customers are affected by particular electrical faults.

And, of course, power companies and utilities will be able to provide cost-effective and timely connections for large amounts of renewable energy. So, overall, they will have a significantly more compelling offering for their customers.

Active Network Management will transform the day-to-day operations of power companies and utilities. Control and field engineers will have ready access to information about the grid through communications systems and clustered databases. This will increase engineer efficiencies, speed up customer response rates, and improve safety. Grid security will also improve as a result.

Power companies and utilities will become proactive rather than reactive. They will continue to increase efforts to identify and repair equipment and lines before failure occurs and shed load to avoid overloading the grid to operate within their established limits. They will also be able to use load control to reduce peak and overall electricity demands.

Active Network Management will also improve the overall efficiency and reliability of electricity delivery by enabling three capabilities: First, more distributed generation, which helps take load off existing distribution and transmission lines. As electricity travels only a short distance before it is used, less energy is lost in transmission and distribution. Second, new demands on the grid. By ensuring that the connection of new forms of consumption, such as heat pumps and electric vehicles, can be visible and controlled, the grid is better able to accommodate customer requirements. Third, energy storage, which reduces the requirements for spinning reserves to meet peak power demands. This makes better use of efficient base-load generation and allows greater use of intermittent renewable energy technologies.

The business case for the benefits of such a smart grid is strong. To realize only some of the benefits outlined above would require significant financial investment to build additional carbon-intensive grid infrastructure and take many years to achieve. Active Network Management could fulfill these ambitions for a fraction of the cost, in a shorter timeframe, and with a significantly smaller carbon footprint. Completed and ongoing Active Network Management deployment and demonstration projects provide evidence for a highly attractive benefit-to-cost ratio.

The smart grid will deliver better efficiencies in energy delivery and operations but the transition to smart grid is only just beginning.

The electricity industry is accustomed to long replacement cycles of 30 to 50 years and tight regulatory control. Regulators are taking clear steps now to support the transition and enable deployment of new grid-management schemes such as Active Network Management.

To date, this support has mainly taken the form of providing various funding mechanisms and incentives for discrete projects or change programmes. However, the expectation is that, as the regulatory framework changes to encourage greater innovation, power companies will adopt Active Grid Management as part of business as usual.

Power companies and utilities are likely, at least in the short term, to take a phased and scalable approach to building the smart grid, trialing different elements of new grid management systems as they go. Even in the longer term, with the benefit of a more-supportive regulatory and funding environment, a smart grid will take time to achieve and new obstacles will appear along the way. Power companies and utilities will want reliable, clearly defined, appropriate, extensible, and flexible plans, not only to the specific challenges outlined here, but also to evolving requirements as they start to feel the many affects and full implications of the low-carbon transition.

www.smartergridsolutions.com

Optimizing output noise through low-noise power design

Active filters outperform traditional LC sections in noise-sensitive power-supply applications

By: Brian Huffman, Sr. Strategic Application Engineer and Roel van Ettinger, Analogue Design Engineering Manager, Micrel

The proliferation of portable connectivity devices over the last decade has seen most of us become more reliant on technology than ever before. At home and at work, as we embrace technology, we demand convenience, ease of use, and optimized reliability and performance. These demands, allied to increasingly compressed design cycles, present challenges for design engineers, one of the most significant being the issue of the noise performance of power supply rails and the adverse effect that this can have on end-device functionality. Here, we examine the issue of signal noise, and a novel platform that addresses the issue in a single form factor. We will also explain how this same technology can apply to an LDO (low dropout) linear regulator to achieve unmatched PSRR (power-supply-rejection ratio) performance from DC to 10 MHz.

Incumbent issues

Traditional power components, for example, the DC-DC converters used in high-performance consumer devices such as GPSs, mobile phones, and image sensors, in many cases no longer offer the performance levels that their applications require. As the microelectronics industry continues to evolve, new generations of devices will require extremely low-noise power-supply lines, especially within RF sections. This is vital for the effective and reliable performance of these devices and for avoiding annoying breaks, malfunctions, and service drops due to a poorly performing power converter.

In GPS applications, for example, the receiver is highly sensitive and may need to decode very low-power signals on the order of −160 dBW. Power-supply noise increases the GPS signal acquisition time and reduces position accuracy, which can have an obvious affect on performance. In mobile phones, supply noise can cause dropped calls and reduce signal strength, problems consumers are no longer willing to tolerate in a highly competitive market. Image sensors also benefit from a *clean* power supply with greatly improved signal-to-noise ratio delivering higher image quality. In these noise-sensitive systems, additional power supply filtering is a vital engineering consideration to meet these most stringent design requirements. Camera modules and image sensors require very wide dynamic range, operating from daylight to nighttime conditions. Low power-supply noise and ripple help to improve this.

To achieve the desired cleanliness of power lines, conventional wisdom dictated filtering implementation by simple LC filters in the supply lines. The purpose of these filters is to reduce the switching regulator's ripple voltage. With skilled circuit design and PCB layout, the output ripple of a buck regulator is typically one percent of the output voltage. For example, one could reasonably expect a 2.5-V output to produce about 25 mV of output ripple. The LC filter attenuates the switching regulator's output ripple. A simple output filter can reduce this noise by anywhere from 20 to 40 db—factors of 10 to 100—and any high frequency spikes which may be superimposed on the ripple are attenuated by even more (**reference 1**). This incumbent method is not perfect and presents challenges to designers in environments where PCB real estate comes at a premium, adding pressure to reduce component footprint as much as possible while maintaining desired performance.

Optimizing noise attenuation

To address the ongoing issue of output ripple, significant work has taken place to develop means of noise attenuation while offering significantly more stable performance in a reduced footprint. Goals include a low cut-off frequency to achieve sufficient suppression and noise reduction on critical supply rails with a single pole LC filter, which to this point has meant using a multitude of space and cost-consuming LC filters.

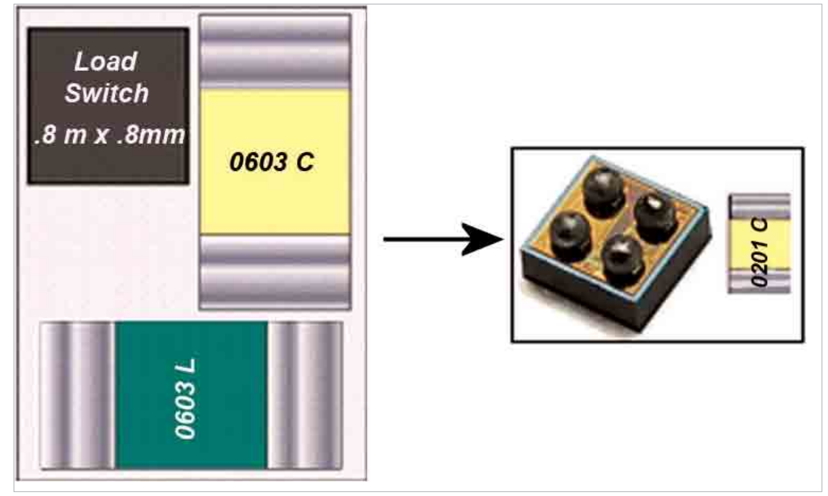


Figure 1: Micrel's MIC94300 integrated design reduces the combined footprint of filter and load switch by as much as 65%.

In portable applications, a semiconductor switch is also required to save power, a factor that previously increased the required PCB board area. An example of single-chip device that combines both the filter and switch is the MIC94300, which Micrel calls the *Ripple Blocker*. This active filter provides high-frequency ripple attenuation and switching noise rejection. Comprising an active filter integrated into an LDO linear regulator and load switch, this topology makes a significant difference in numerous high-volume consumer products such as mobile and smart phones and tablets in terms of enhancing performance and sustaining connectivity integrity.

The main advantages of designing active, rather than passive, filters into power supplies are threefold. Firstly, the integration of the active filter in the silicon offers significant savings in terms of component count and PCB real estate. In this case, the single-chip design reduces the PCB footprint by as much as 65% (**figure 1**). Active filters also provide the capability to implement multiple order filters or achieve a certain filter passband shape or lower corner frequency virtually independent of package size.

Another advantage active filters have over LCs is their superior transient response and avoidance of the ringing effect LC filters often experienced. This puts less demand on load circuits' PSR (power supply rejection) and reduces cross coupling to sensitive adjacent nodes.

An active-high enable pin controls the MIC94300's load switch. Forcing the enable pin low turns off the load switch, setting it to a near-zero off-mode current state. When enabled, the load switch is biased near its saturation region to maintain optimum performance between low $R_{DS(ON)}$ and ripple rejection. The result is roughly a 170-mV fixed voltage drop between the input and output voltages. The IC protects itself from damage due

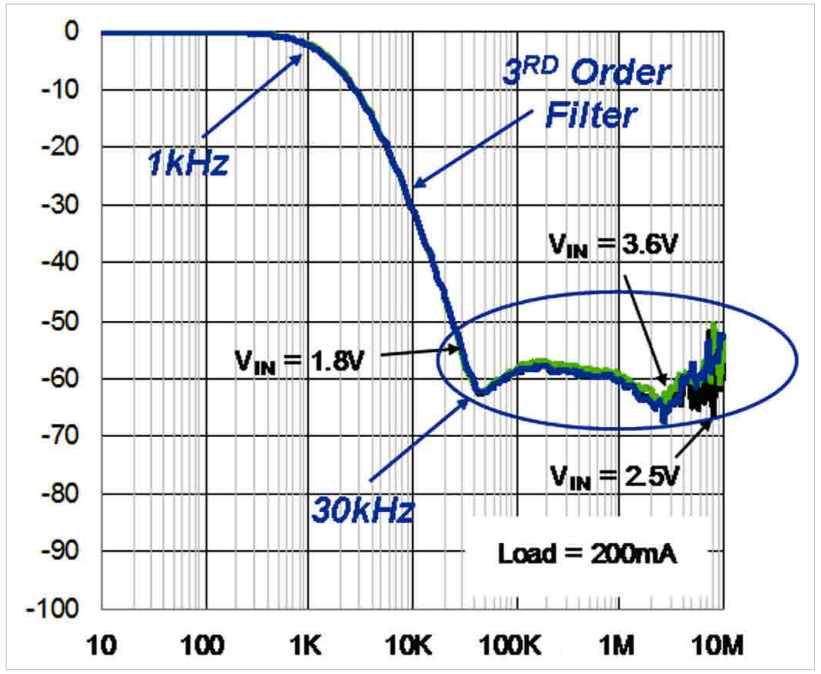


Figure 2: PSRR (dB) vs frequency (Hz) for the Micrel MIC94300 operating with COUT = 1µF, showing high frequency PSRR results in the 30 kHz to 10 MHz spectrum.

to fault conditions, offering linear current limiting and thermal shutdown. The device achieves a supply-noise attenuation of about 60 db—a factor of 1000—from 30 kHz to 10 MHz, constituting a tenfold improvement over the LC filter at a switching frequency of 300 kHz (**figure 2**).

The internal active filter passes DC and blocks any AC components with a frequency beyond 1 kHz. A third-order filter provides a steep roll-off so that most of the attenuation is available from 30 kHz to 10MHz. This means that, for the designer, virtually all switching-regulator output-ripple components will reduce by about 60 dB, which is a vast improvement in design margin in any portable design compared to incumbent technologies. The IC maintains its low 170-mV drop over varying loads, optimizing power efficiency. Most available LDOs will not produce this level of PSRR for such a small voltage drop over such wide bandwidth while consuming just 140 µA of ground current.

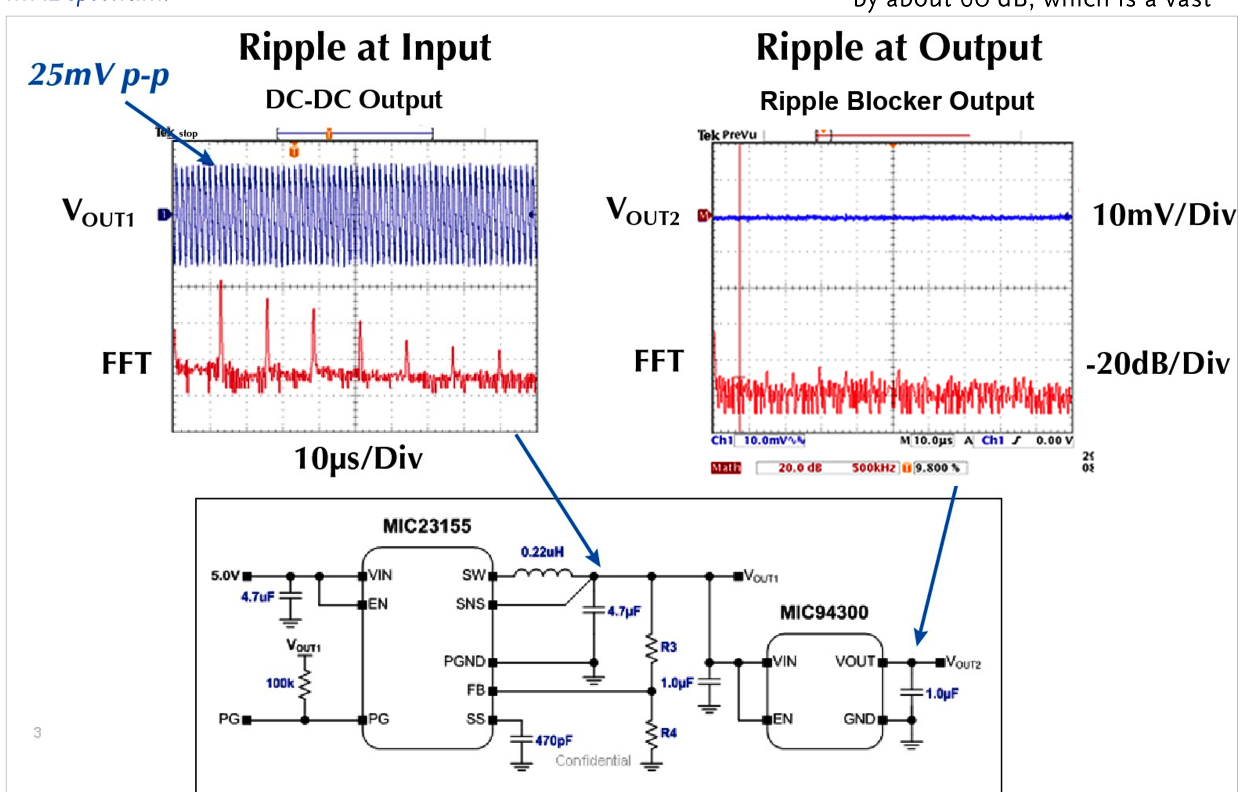


Figure 3: Typical application example showing ripple reduction.

Applications in capacitive touch sensing using this method as a very low-noise and -ripple power source benefit from improved sensor accuracy, and there are a wide range of emerging applications that will use capacitive-sensing technology, including smart phones and tablets. Motor applications using Hall Effect devices detect the rotation angle of small brushless DC motors. Eliminating noise at the power source of the Hall Effect device improves the Hall sensors' precise signal response over operating range and the performance of the motor.

A typical application illustrated

An example of a typical application circuit includes an MIC23155 synchronous-buck switching regulator and an MIC94300 (**figure 3**). The buck regulator steps down the 5-V input to 2.5 V. The regulator's switching action creates the output ripple that appears on the output capacitor. The magnitude of the output-voltage ripple depends upon the inductor ripple current, the output capacitance value, its ESR (effective series resistance), and its ESL (effective series inductance). The circuit achieves a 25-mV peak-to-peak ripple across the output capacitor. The fundamental frequency of 314 kHz is the switching frequency of the buck regulator, with harmonics being multiples of the switching frequency.

The MIC94300 provides a more than 40 dB improvement in rail noise over the spectrum of interest. The ripple at the output is near to zero with switching harmonics virtually eliminated, as the low $R_{DS(ON)}$ of a current limit switch combines with the PSRR capability of an LDO. First, the LDO maintains a fixed voltage drop of 170mV that is independent of load current. An internal 170mV referenced to the input voltage sets the voltage drop. A low-pass filter passes the DC and blocks the AC component of the input voltage. The filtered signal serves as a reference to the LDO so the output will follow the DC of the input but rejects any AC signal. The use of an NMOS pass device provides an extremely low dropout as used in current limit switches. This technology can also apply to LDOs to produce fixed output voltage with high PSRR from DC to 10MHz. Here the device regulates the output voltage like a basic LDO regulator, where a resistor-divider network connecting the output and ground sets the output voltage.

Standard P-channel LDOs have high PSRR at DC but start losing ripple rejection typically above 10 kHz. This roll-off is due to the gain-bandwidth limit of the error amplifier. The MIC94310 does not have this limitation because it uses an NMOS pass device configured as a source follower and has intrinsically good PSRR due to its low output impedance. This means that a smaller loop gain is necessary to achieve the same PSRR as when using a PMOS as a pass device. Therefore, at higher frequencies where the loop gain drops, an NMOS pass device can still maintain a good PSRR.

The MIC94310 surpasses the performance of a standard LDO at frequencies from 1 kHz to 10 MHz. This type of product is, therefore, highly suitable for use as a regulator with a switching regulator input voltage whose fundamental switching frequency is typically in the 500 kHz to 3 MHz range.

www.micrel.com

References:

1. Nelson, Carl, *LT1070 Design Manual*, Application Note 19, Linear Technology.

Duty-ratio feedforward control of digitally controlled PFC

Duty-ratio feedforward control of digitally controlled PFC

By: Bosheng Sun, System Engineer, Texas Instruments

PFC (power-factor correction) circuit designers have used average current-mode control for decades (**figure 1**). Various analog PFC-control chips based on this control algorithm are available in the commercial market.

The performance of average current-mode control often is considered adequate for most commercial power applications with 50 or 60 Hz AC line input. However, the traditional average current-mode control causes the inductor current to lead the input voltage, resulting in a non-unity fundamental displacement power factor and zero-crossing distortion. This situation gets worse with PFC operating in a high-frequency AC environment, such as 400 Hz, often used in airborne systems. The high input-current quality required in these systems is difficult to achieve

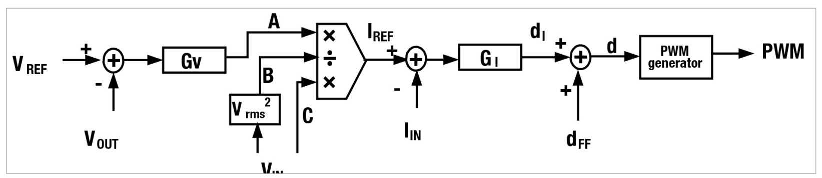


Figure 2: Duty-ratio feedforward control for PFC

through traditional control methods. A new control method, called DFF control, effectively can reduce input-current distortion under high line frequencies (**references 1, 2,** and **3**).

Duty-ratio feedforward control

The basic idea of DFF control is to pre-calculate a duty ratio to alleviate the feedback controller of the task. For the boost topology operating in continuous conduction mode, the duty-ratio, d_{FF}, is:

$$d_{FF} = \frac{V_{OUT} - V_{IN}}{V_{OUT}} \quad \text{(Eq. 1)}$$

This duty-ratio pattern effectively produces a voltage across the switch, the average of which, over a switching cycle, is equal to the rectified input voltage. A regular current loop compensator changes the duty ratio around this calculated duty-ratio pattern. Since the impedance of the boost inductor at the line frequency is low, a small variation of the duty ratio produces enough voltage across the inductor to generate the required sinusoidal current waveform (**figure 2**).

The feedforward duty ratio, d_{FF} calculated in Equation 1 adds to the traditional average current-mode control output, d_I. The circuit uses the final duty ratio, d, to generate a PWM waveform to control PFC.

Digital implementation

Figure 3 is a block diagram of the digital implementation of this DFF control for a single-phase PFC. A signal conditioning block senses the input voltage, V_{IN}, before the bridge rectifier. The block senses the line and neutral separately by two ADC channels. They are then rectified by firmware to get rectified

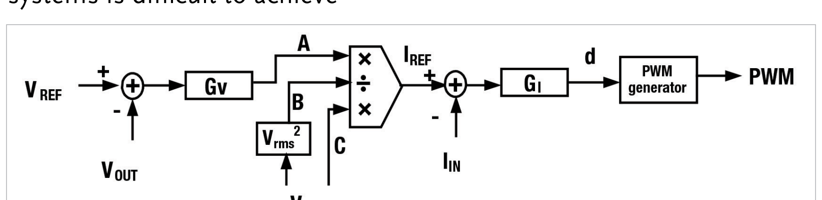


Figure 1: Average-current-mode control for PFC

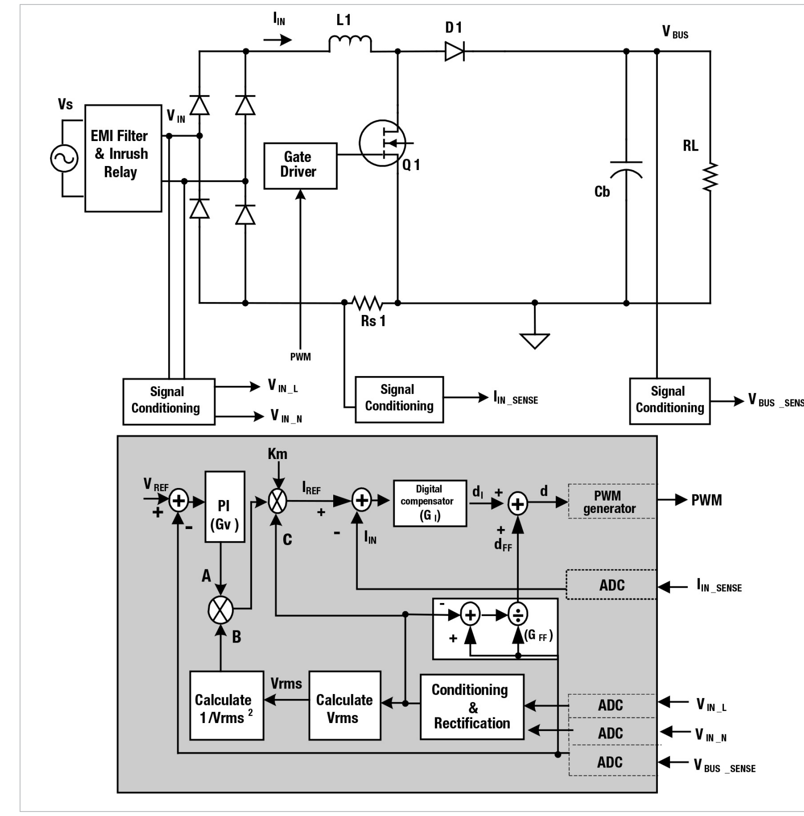


Figure 3: Duty-ratio feedforword control digital implementation

V_{IN}. Another ADC channel senses the PFC output voltage, V_{OUT}. A resistive shunt senses the current signal and its feedback signal I_{IN_SENSE} serves as an input for current loop control. Note the use of three controllers: Voltage loop GV, traditional average current-mode GI, and a DFF GFF.

The voltage loop controller, GV, can be quite simple. The controller compares the V_{OUT} measurement with a reference. The error goes to a pure firmware PI (proportional-integral) controller. Its output, depicted as *A* in Figure 3, is used for current reference calculations. To meet the transient-response requirement, a nonlinear PI controller is necessary. **Listing 1** is an example of a firmware nonlinear PI controller.

```
//nonlinear PI controller
//if error is small, use small gain
if (abs(error) < error_threshold)
{
   p = kp * error;
   i = i + (ki * error);
}
//if error is large, use big gain
else
{
   p = kp_nonlinear * error;
   i = i + (ki_nonlinear * error);
}
```

Listing 1

The traditional average current-mode controller GI regulates the inductor current so that the input current follows the input voltage. To do this, first calculate the current reference. For an average current-mode controlled PFC, calculate the current reference as:

$$I_{REF} = Km \cdot A \cdot B \cdot C \quad \text{(Eq. 2)}$$

where Km is the multiplier gain, A is the voltage loop output, B = 1/V_{rms}^2, and C is input voltage, V_{IN}.

The circuit measures the components of V_{IN}—line and neutral—separately by two ADC channels. Firmware then rectifies the digital representation of the waveform (**listing 2**).

```
//rectify Vin measurement
//if positive half cycle
if (Vin_L > Vin_N)
{
   Vin = Vin_L - Vin_N;
}
//if negative half cycle
else
{
   Vin = Vin_N - Vin_L;
}
```

Listing 2

By definition, the RMS value is:

$$V_{RMS} = \sqrt{\frac{1}{T_{ac}} \int_{t=0}^{t=T_{ac}} V(t)^2 \, dt} \quad \text{(Eq. 3)}$$

which in discrete form is:

$$V_{RMS} = \sqrt{\frac{1}{N} \sum_{n} V(n)^2} \quad \text{(Eq. 4)}$$

The sampled V_{IN} is squared and accumulated in each AC cycle, then divided by the number of samples to get V_{RMS}^2.

Once the system calculates the current reference, it compares that value to the current feedback signal. The digital error information passes to a digital compensator for current loop compensation. The digital compensator could be firmware- or hardware-based, a traditional PID (proportional-integral-derivative), or a two-pole two-zero structure.

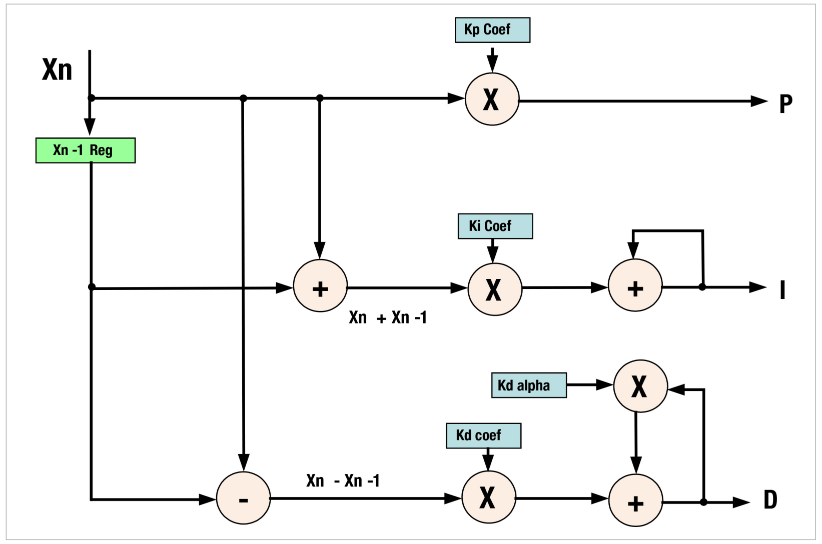


Figure 4: A second-generation digital-power-controller PID structure, based on the UCD3138

A discrete-time implementation of a PID controller calculates the three terms:

$$U_P(n) = K_P E(n) \qquad \text{(Eq. 5)}$$
$$U_I(n) = U_I(n-1) + K_I[E(n) + E(n-1)]$$
$$U_D(n) = K_D[E(n) - E(n-1)].$$

An example of a discrete-time two-pole two-zero controller expression is:

$$\frac{U}{E} = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}} \qquad \text{(Eq. 6)}$$

A regular average current-mode control uses its output, d_I, to generate a PWM pulse to control PFC. However, a D_{FF} control only uses that output to compensate for the difference between the current reference and the real inductor current generated by DFF. The DFF controller G_{FF} uses equation 1. Firmware adds d_{FF} with d_I to get the final duty term d. The final duty term, *d*, goes into a PWM module to generate the corresponding PWM pulse.

Enhanced duty-ratio forward control

A DFF controller calculates d_{FF} based on V_{IN} and V_{OUT}, then adds d_I to get the final value for d. All these calculations execute in firmware so the CPU's speed determines the control-loop speed, which then affects the loop bandwidth. A faster CPU can achieve a higher bandwidth. However, the faster CPU is also more expensive and dissipates demands more power.

Given a low-cost digital controller with a clock frequency of 30 MHz, a 50-kHz interrupt loop can implement the current-loop control. This includes ADC measurements, V_{RMS} calculation, current-reference generation, and duty-ratio calculation. All these tasks need to execute in 20 µs. Further increasing the interrupt-loop speed causes it to overflow. With this setting, the current-control loop is running at a speed of 50 kHz. The bandwidth normally is less than one-tenth of the control loop speed. Thus, the bandwidth is less than 5 kHz, which is relatively low for PFC current regulation.

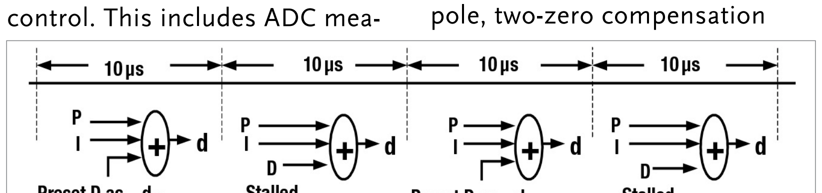


Figure 5: Enhanced duty-ratio feedforward structure

Referring again to figure 3, although the CPU calculates I_{REF} and d_{FF} at 50 kHz, the digital compensator and PWM generator are hardware, so they can run at a much faster speed, for example, 100 kHz. This means that the system can calculate d_I at 100 kHz. So it is really the sum $d_{FF} + d_I = d$ that slows down the control loop speed. If hardware can implement the $d_{FF} + d_I = d$ sum as well, then the whole loop is faster than before, and the bandwidth is improved.

This is possible with second-generation digital power controllers such as the Texas Instruments UCD3138. The digital compensator in this device is a traditional PID structure with an extra alpha to provide two-pole, two-zero compensation (**figure 4**). P, I and D are three separate branches. Their outputs add to generate a final control signal. Since PFC current loop is a first order system, normally a PI controller is enough for the compensation. This leaves the D branch spare, which could be used to improve the DFF control speed.

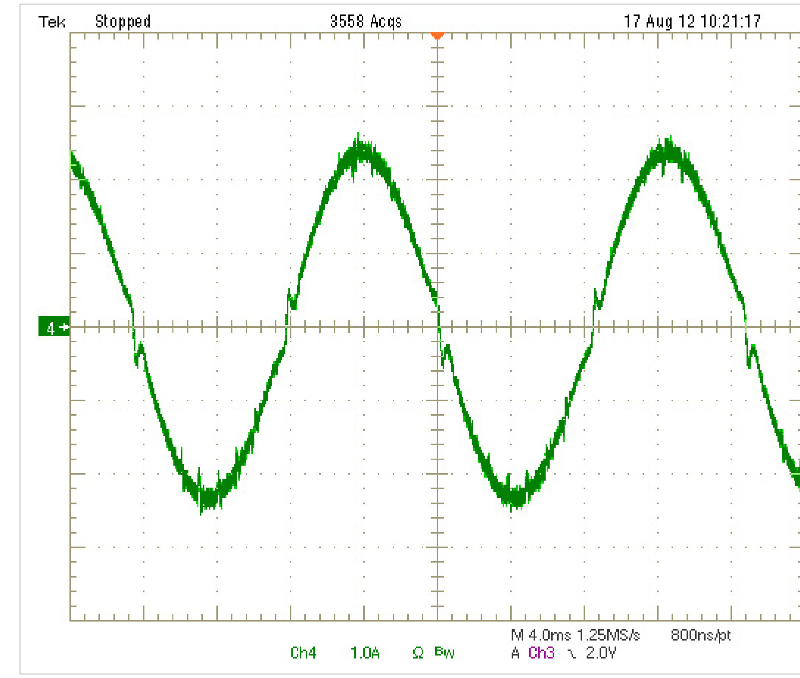


Figure 6: Line current with DFF control: V_{IN} = 110 V, load = 180 W, THD = 4.04%, PF = 1

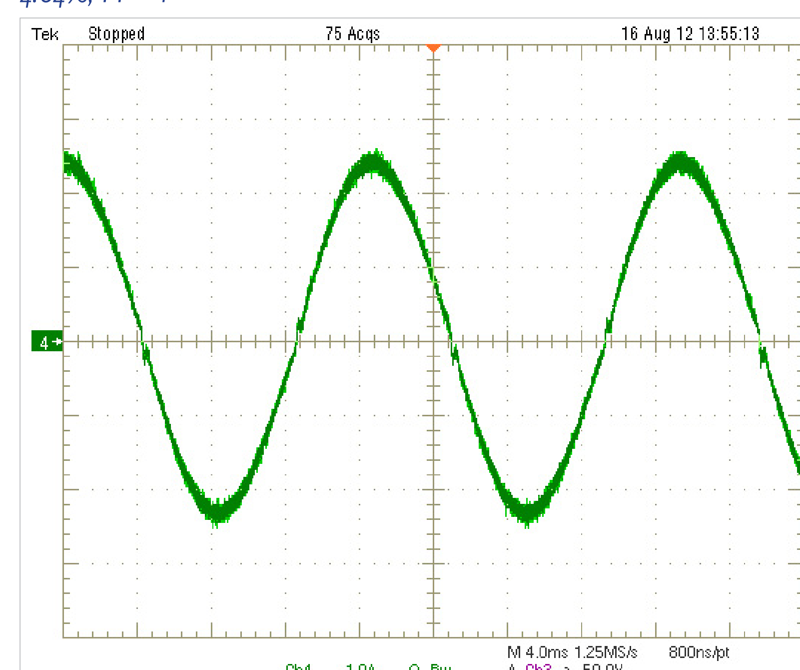


Figure 7: Line current with enhanced DFF control: V_{IN} = 110 V, load = 180 W, THD = 1.9%, PF = 1

The D branch has two advanced features. First, its output can be set to a predefined value. Second, it's output can be stalled or frozen at its current value. With these two features, we can still calculate d_{FF} every 20 µs, then preset the D branch output at this d_{FF}, then stall it. Although d_{FF} is calculated at 50 kHz, the P, I, and d = P + I + d_{FF} is running at 100 kHz, and the PWM output updates at 100 kHz. So the effective control loop is running at 100 kHz, double the loop speed before (**figure 5**). With this faster control loop speed, the bandwidth can push higher and, consequently, THD and PF improve.

Experimental results

Texas Instruments engineers tested the DFF and its enhanced version on a 360-W single-phase PFC. Waveforms from these two different controllers, operating under the same test conditions, show that the enhanced DFF control makes the AC current waveform much smoother and improve THD from 4.04% to 1.9% (**figures 6** and **7**). **Table 1** shows the THD and PF difference under these two controls.

The improvement results from the increased bandwidth with enhanced DFF control. **Figure 8** shows the bode plots for these

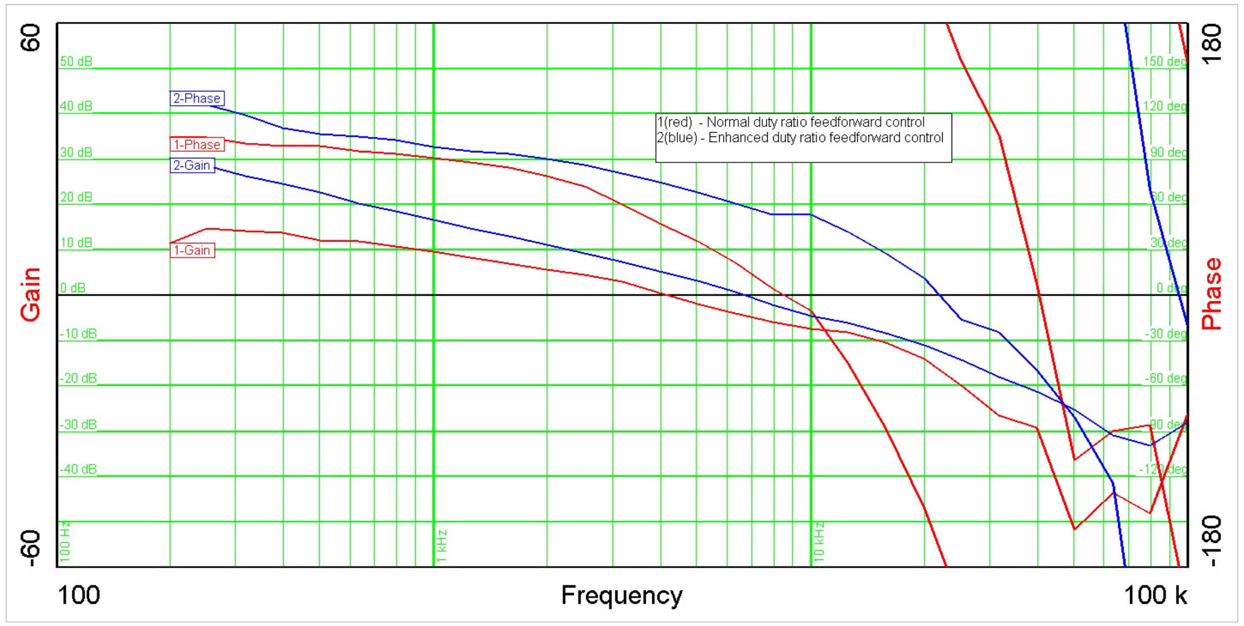


Figure 8: Bode plot comparison between a normal DFF and an enhanced DFF

		Traditional average current-mode control		Enhanced duty-ratio feedforward control	
V_{IN} (V)	P (W)	THD (%)	PF	THD (%)	PF
110	30	10.85	0.99	11.81	0.99
	60	6.97	0.99	7.56	1
	180	1.98	1	1.88	1
	330	1.51	1	1.45	1
230	30	8.75	0.9	11.47	0.933
	60	6.13	0.96	6.95	0.98
	180	2.96	0.99	3.34	1
	330	2.28	1	2.41	1

Table 1: THD and PF comparison between average current-mode control and enhanced DFF

two cases. For a fair comparison, the PID control gains are set to be the same. With the enhanced DFF, the bandwidth increases from 4.3 to 8.5 kHz, and phase margin increases from 25° to 50°.

DFF and average current-mode comparison

It is interesting to see the difference between this enhanced DFF control and a traditional average current-mode control. For a fair comparison, TI engineers tested these two control methods with the same PFC unit and the same PID gain for G1. Table 1 shows the THD and PF under these two cases. Note that the DFF control gives better PF, but worse THD. For applications with strict PF requirements, the enhanced DFF is a better choice.

www.ti.com

References

1. Van de Sype, DM, et al, *Duty-ratio feedforward for digitally controlled boost PFC converters*, IEEE Transactions on Industrial Electronics, vol 52, nbr 1, Feb 2005.

2. Chen, M and J Sun, *Feedforward current control of boost single-phase PFC converters*, IEEE Transactions on Power Electronics, vol 21, nbr 2, Mar 2006.

3. Prathapan, PT et al, *Feedforward current control of boost-derived single-phase PFC converters*, APEC vol.3, 2005.

Smart-grid security: history demonstrates need

Evolution increases security risks

By: Dave Andeen, Strategic Segment Manager for Energy, Maxim Integrated

The smart grid surrounds us these days. In the U.S., approximately 36 million smart electricity meters have deployed since 2007 (**reference 1**). In Europe, both Italy and Sweden have each achieved complete smart-meter installations (**references 2** and **3**). Spain is actively deploying, while the rest of Europe and Asia are all on the verge of massive deployments (**reference 4**). Utilities in North America, Europe, and China are aggressively upgrading their DA (distribution-automation) infrastructure with smart-enabled devices including line sensors and distribution controllers enabled with communication. In a relatively poor global economy, smart-grid projects shine with bright success and infrastructure renewal.

Success often makes us comfortable—even complacent—about the day-to-day operation of our systems. Looking forward to even more deployment, we tend to avoid hard, worrisome questions about the long-term effects of the movement. A particular thorny question for the evolving smart grid is security. Where? How much is enough? I know a former utility employee who recently asked me, "If we network all of the electricity meters and grid infrastructure, can someone write a computer virus and take down the entire grid?" My answer was, "Yes."

To gain insight into these smart-grid security questions, consider two recent well-documented security breaches and a report of a security gap. These situations include a 2009 smart-meter hack in Puerto Rico, a 2012 password discovery in grid distribution equipment, and insecure storage of a private key in distribution automation equipment. For each of these attacks, secure silicon methods exist that, as part of a complete security strategy, can help thwart the attacks.

Security risks on the rise

Whether a computer virus can take down an entire electricity grid is entirely up for debate, and beyond the scope of this article. Furthermore, the security world abounds with threats and worst-case scenarios. As of now, most smart meter communication occurs in a query-and-respond manner. The data exchange is simple and with minimal control functionality. Critical switching on the distribution grid occurs over different networks, protected by high voltage.

The grid is evolving, however, right in front of us. In fact, the widespread deployment of the smart grid is increasing the opportunities for hardware and cyber attack. As with all communication networks, connectivity enables functions and applications that consume more bandwidth. Connectivity makes access to the system functionality simpler. The drive toward using IP (Internet protocol) to achieve interoperability will create robust networks that operate at low cost, but ones that are just as vulnerable to attack as in the Internet. As with corporate data, now critical grid functions, such as switching, remote disconnect and volt/VAR optimization, will migrate to these networks. Wonderful technical advances for the grid, yes, but along with them come new vulnerabilities.

With smart meters and grid distribution communication becoming more pervasive, we must anticipate critical threats.

We must also assess the security breaches that have already occurred in the smart grid. What can we learn from them? What protections can equipment suppliers and grid operators proactively design into smart grids to thwart those attacks and others to come?

Securing manufacturing

In 2009 employees at an electricity-meter manufacturer in Puerto Rico hacked smart meters by accessing the meters through their optical ports. The U.S. FBI reported that the meter manufacturer's employees and utility employees were both altering meters and training others to alter meters; their payoff was $300 to $1000 in cash per meter. U.S. federal authorities estimate that the Puerto Rican utility losses could amount to $400 million and that future attacks are likely (**reference 5**). Although the exact security mechanisms, or lack thereof, at the manufacturing site are unclear, one fact is undeniable: manufacturing employees could gain access to a meter.

Most companies use third-party manufacturers for some or all of their product manufacturing. While wealthier, established companies put tight controls on these manufacturers, smaller equipment makers often do not, or cannot, closely control their supply chain. As a result, their products are at higher risk of a security breach.

Strong authentication protocols are one highly effective method for avoiding the type of attack witnessed in Puerto Rico. In authentication, two communicating parties verify their identity and, thus, trust their communication. Individual passwords serve as the most basic forms of authentication. Any communication from an unauthenticated party, such as a hacker, is ignored. But what happens when a perpetrator uses a discovered password to gain system access?

A typical password-protected static system uses the same password every time. A dynamic system, in contrast, achieves higher levels of authentication. As described by Jones, here the host generates a random number as a security challenge whenever a party requests access (**reference 6**). The requestor must then respond with an answer generated from that random number, the message that it is trying to send, and a secret key. The host compares the response to its random number challenge with an internally generated response. The two responses must be equal, but every subsequent response will be different, because each is based on the random number generated by the host.

The system's mathematics underlying this challenge and response are such that a party intercepting the response has virtually no possibility of decoding the secret key from that information. The dynamic nature of the system ensures that the communications are unique each time. The SHA-1, SHA-2, and SHA-256 algorithms are all excellent examples of this type of dynamic authentication.

The most valuable information in the challenge-and-response authentication process is the secret key. Additional techniques to further strengthen the authentication process include generating secret keys on physically secure chips, such as the MAXQ1050, and generating keys in stages. These methods ensure that no single party retains access to all the building blocks of the keys. A combination of the integrated and staged key generation provides even better security.

Single or multiple keys and asymmetric schemes

In August of 2012, Justin Clarke reported a security flaw in the operating system of RuggedCom's ROS (Rugged Operating System). RuggedCom products provide ruggedized network timing and communications infrastructure for electricity transmission and distribution, as well as other industrial applications. Clarke's report asserted that an attacker could use a single key to penetrate the inner workings of the ROS (**reference 7**). Once inside, the attacker could easily view communication traffic without additional security barriers. Furthermore, an attacker could obtain a key from any piece of RuggedCom equipment and use it to access any other piece of their equipment.

The issue at hand relates to a single secret key. Systems employing a symmetric encryption algorithm will use a single private key for encryption and decryption of data. Any device with the private key may join the network, similar to a conference call in which participants use the same code to enter the discussion. Because of their sheer volume, smart-grid devices, and smart meters specifically, create a challenge with symmetric encryption schemes. The millions of smart meters and pieces of distribution automation equipment installed on the grid mean that the holder of that single secret key can potentially access each piece of equipment. The security threat is obvious. Shutting off power and causing massive outages in areas of critical infrastructure or high population represents the worst potential outcome. Furthermore, this is a minimal effort attack with potentially dire consequences.

An asymmetric certificate-based security scheme blocks this type of attack. Asymmetric schemes consist of a public/private key combination for each end device. Each key works to mathematically encode or decode a message. All network devices know each other's public key and may use it to encode a message directed to a specific device. That specific device then uses its private key to decode the message. Secure ICs generate private keys completely on chip, store them in secure memory, and never reveal them. Managing entities, such as utilities, then also give each device a certificate that establishes a chain of trust within a network. In this way the meter becomes associated with an access point, which authorizes the meter and allows it to join the network. Each certificate should be unique, based on an individual identification number or other unique identifying characteristic. This scheme, therefore, provides the benefit of asymmetric encryption, never revealing either private keys for the many devices on the grid or network or the individual identification of each device.

Protecting keys

On September 19, 2012, the ICS-CERT (Industrial Control Systems Cyber Emergency Response Team) reported another security gap in distribution automation equipment (**reference 8**). In this incident the private key, used for signing certificates, was insecurely stored on a PLC (programmable logic controller). The private key was the certificate authority's private key, so any device obtaining the private key could certify itself as a valid device in the network. The attacker could then execute a *man in the middle* attack in which the attacker intercepts communications, certifies itself as a valid system device, and proceeds to gain network access. Initial resolution of the issue required uninstalling certificate authority signing keys and manually confirming the identity of each device on the network. This resolution method works in a smaller network, but it would require a massive expense and effort for a multimillion-device network.

Key management is the most difficult aspect of security because key access means key exposure, to systems or people. Exposing keys greatly increases risk of theft. The first line of defense in protecting keys is, therefore, to generate them once, in a physically secure IC, and never let them off the chip. A device on the smart grid can effectively use keys stored in such a way and never reveal them.

In addition to on-board key generation, encryption, and software security, there is also the matter of physical device security, which provides many effective techniques for securing keys. When tamper-detection pins on secure ICs sense interruptions of specific signals between pins electronically connected to equipment access points, the IC reports a physical tamper event. Systems respond to tamper events as programmed. Actions range from logging the event to erasing secret keys, hence rendering the system inoperable, which is common in financial terminals, but generally not acceptable in smart grid.

Protective meshes and temperature monitoring are other mechanisms for detecting efforts to decap a secure silicon device to retrieve secure keys. Meshes physically protect the top of a secure device from a probing attack. Temperature sensors detect events such as pouring of liquid nitrogen on a device to force the retrieval of a key from memory. Secure memory design also includes mechanisms for eliminating retention and imprinting of key data because of material stress over time. Overall, storing keys in a secure IC instead of the general-purpose RAM of a connected device like a PLC provides the ultimate level of security for those keys.

Cyber attacks on the rise

The real scenarios in this article represent the tip of the proverbial iceberg. In July of 2012, the top U.S. military official responsible for defense against cyber attacks, General Keith B. Alexander, reported a 17-fold increase in cyber attacks against American infrastructure from 2009 to 2011 (**reference 9**). GlobalData reported in September of 2012 that the cyber security market in China will increase from $1.8 billion in 2011 to $50 billion in 2020 (**reference 10**).

The smart grid is an undeniable trend. Countries and utilities are working to establish better control over their electricity resources, shave peak demand, operate more efficiently, and accommodate massive amounts of distributed resources. The smart grid also becomes the major litmus test for future Internet networking of things, a proving ground for a network of millions of smart meters. Knowing all this, equipment and meter manufacturers must consider security as a critical, system-level requirement when developing smart-grid devices. There is no doubt that multilayered, life-cycle hardware and software security are the best means for keeping smart grids operational.

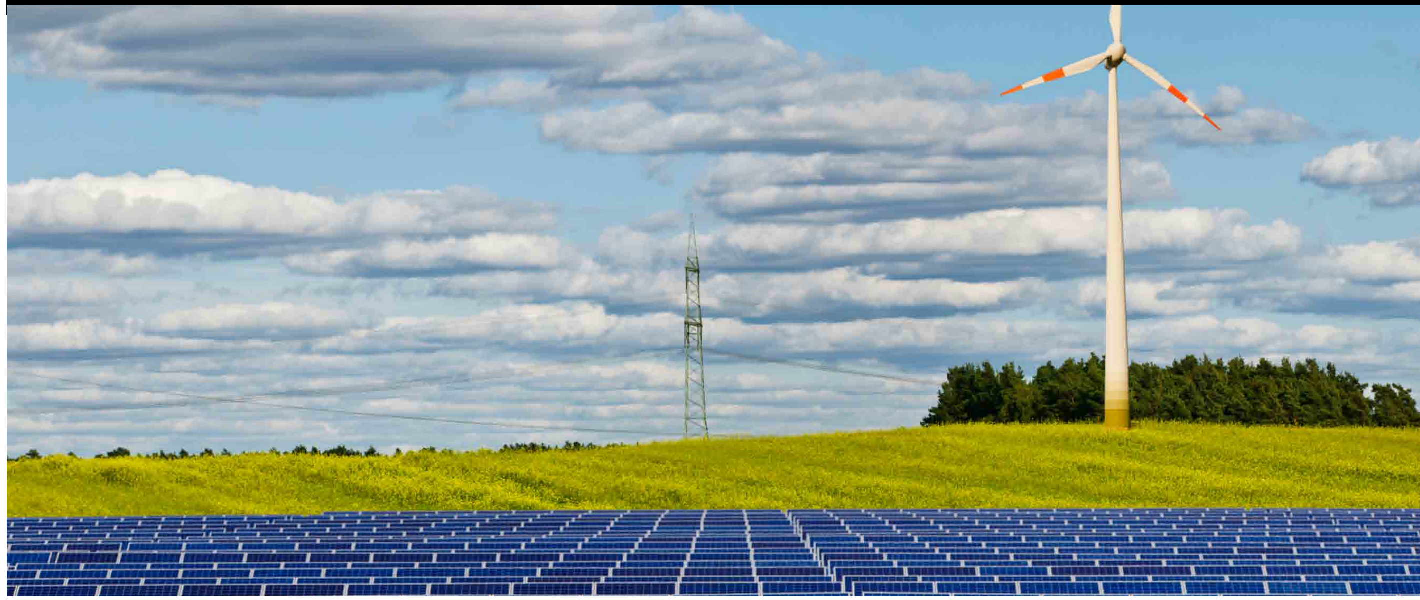
www.maximintegrated.com

References:

1. Institute for Electric Efficiency, *Utility-Scale Smart Meter Deployments, Plans, & Proposals*, IEE Report, The Edison Foundation, May 2012. www.edisonfoundation.net/iee/Documents/IEE_SmartMeterRollouts_0512.pdf.
2. Tweed, Katherine, *Smart Grid Italy: What to Watch*, GreenTechGrid, 10 Aug 2011. www.greentechmedia.com/articles/read/smart-grid-italy-what-to-watch.
3. *Sweden at forefront of demand response in Europe*, eMeter, 17 Aug 2010. www.emeter.com/smart-grid-watch/2010/sweden-at-forefront-of-demand-response-in-europe.
4. *Iberdrola to deploy an additional one million smart meters in Spain*, Telecom Engine, 20 Mar 2012. www.telecomengine.com/article/iberdrola-deploy-additional-one-million-smart-meters-spain.
5. Krebs, Brian, *FBI: Smart Meter Hacks Likely to Spread*, Krebs on Security. www.krebsonsecurity.com/2012/04/fbi-smart-meter-hacks-likely-to-spread.
6. Jones, Scott, *Protecting R&D Investment with Secure Authentication*, Maxim Integrated tutorial 3675, 19 Oct 2012. www.maximintegrated.com/AN3675.
7. *Siemens software which control power plants vulnerable to hackers*, Homeland Security News Wire, 27 Aug 2012. www.homelandsecuritynewswire.com/dr20120826-siemens-software-which-controls-power-plants-vulnerable-to-hackers.
8. *Siemens S7-1200 insecure storage of https CA certificate*, Advisory ICSA-12-263-0, ICS-CERT, 19 Sep 2012. www.us-cert.gov/control_systems/pdf/ICSA-12-263-01.pdf.
9. Sanger, David E and Eric Schmitt, *Rise Is Seen in Cyberattacks Targeting U.S. Infrastructure*, New York Times, 26 Jul 2012. www.nytimes.com/2012/07/27/us/cyberattacks-are-up-national-security-chief-says.html?_r=3ref=fb&.
10. *China's Cyber-Attack Fears to Spark Massive Defense Spending*, GlobalData, 19 Sep 2012. www.globaldata.com/PressReleaseDetails.aspx?PRID=368&Type=Industry&Title=Smart%20Grid

Special Report: Wind and Solar Power

PSD EUROPE
Power Systems Design: Empowering Global Innovation



INSIDE:

Renewable energy prices; weather driven and volatile

Growing renewable-generation capacity reduces emissions but complicates capacity-planning and energy-pricing models

By: James Cox, Head of Market Analysis, Pöyry Management Consulting

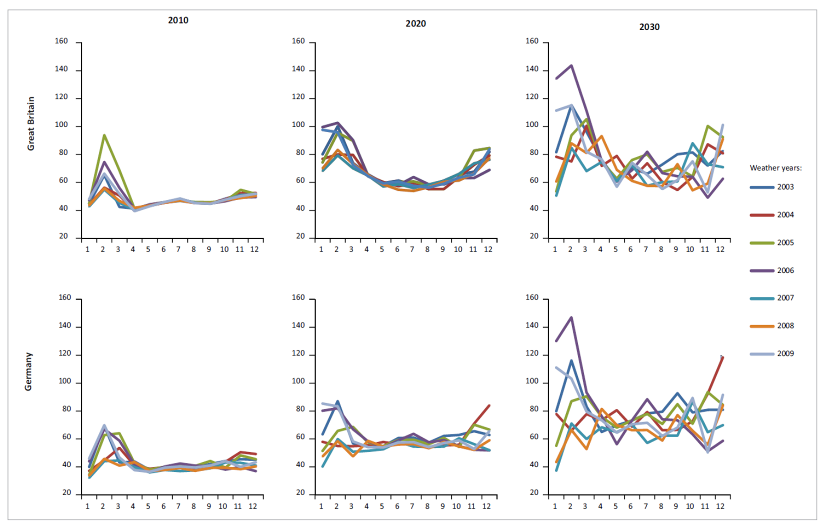


Figure 1: Wholesale energy prices will be increasingly driven by the weather.

Pöyry Management Consulting has conducted a series of studies over the last two years to investigate how European energy markets would need to evolve in the face of the radical changes expected from the introduction of renewable power sources.

James Cox highlights some of the fundamental shifts expected to seen over the next 10 to 20 years if the electricity system becomes increasingly dominated by renewable and other low-carbon generation. These impacts are relevant for electricity and gas markets, given the interlinking between them.

Currently the weather drives energy markets mainly as a result of temperature: Cold temperatures push up gas demand and to a lesser extent electricity demand, which in turn affects prices. Increasing amounts of wind and solar generation connected to the system will significantly increase the importance of the weather, with interactions between temperature and wind generation and between solar output and cloud cover becoming critical (**figure 1**).

The figure highlights this increasing impact by showing monthly average electricity prices for seven different historical *weather years*. Each line shows the price assuming different weather patterns and plant availability, but with everything else—fuel prices, installed plant, et cetera—the same. In 2010, monthly electricity prices are only slightly affected by weather, but by 2020 and 2030, historical weather patterns lead to very different price tracks, still, cold months having much higher prices than wet, windy, warm months.

By 2030, this could mean that some customers choosing to do certain activities based on the weather. Operating washing machines and tumble dryers might become a 'windy weather' activity and people may defer charging electric vehicles during cold, still periods.

The consequence of weather influence will be increased volatility of prices. This is driven partly by the impact of *low-priced periods*, when wind, solar, or nuclear sets low, potentially zero, or even negative prices. This has

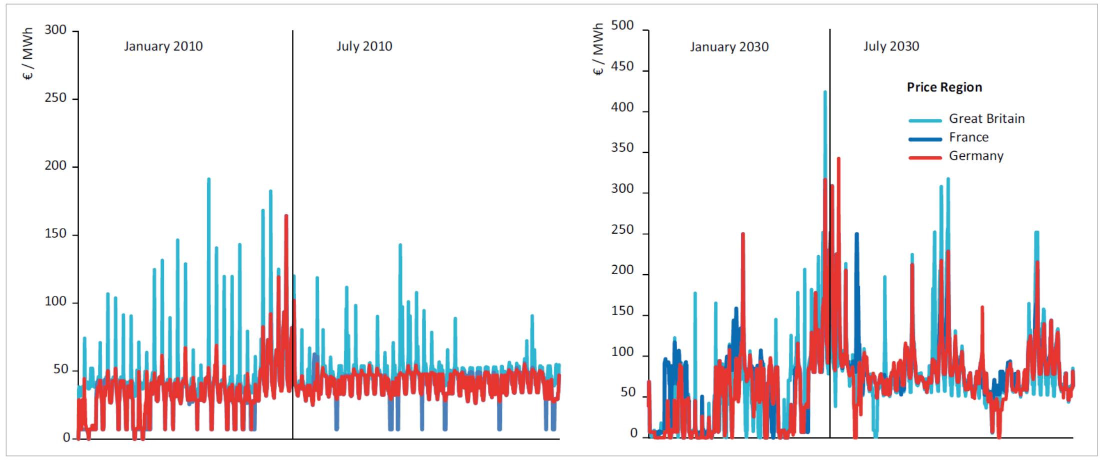


Figure 2: Models suggest that future wholesale hourly prices could exhibit increasing volatility.

been seen in multiple European markets. The starkest example is Spain, where in early 2010, electricity-market prices were zero for 300 hours because of high wind and high hydro generation.

Prices will also become more volatile for a second reason: fixed cost recovery. Power plants recover their annual fixed costs and their return on capital, earning profits in hours when prices are above their short-run marginal costs of generation. Increasing amounts of wind or solar generation in the system means the hours of operation of thermal plants reduce, as the plant is squeezed out of the merit order on windy or sunny days.

Such plant will have to recover the same fixed costs over shorter and shorter time intervals. Prices will have to spike to high levels in these hours to remunerate the plant. Alternatively thermal plant unable to recover its fixed costs, will close down; leading to shortfalls in capacity and spiky prices, due to demand shedding.

Figure 2 depicts how prices could evolve with hourly wholesale-electricity prices in three markets taken from the output of Pöyry's electricity model, Zephyr. It is clear that prices become both more volatile and riskier, with substantial periods of very low or zero prices.

Intermittent thermal generation challenges investment

The intermittent effect of wind and solar generation on the system is to make thermal generation intermittent in operation, with more starts and part loading, and an increasing need to operate flexibly. This is already driving changes in new plants that major turbine manufacturers are marketing, with emphasis now as much on flexibility as on efficiency—an example being the recently released FlexEfficiency50 CCGT (combined cycle gas turbine) from General Electric.

More volatile prices and *intermittent* operation for thermal plants combine so that investing becomes much more risky, affecting the investment decision through higher hurdle-rate requirements. That could lead to capacity shortfalls, as electric-energy providers cannot economically build new generation facilities.

There is serious concern in many countries that existing market designs may not be fit for purpose, witness the UK's DECC (Department of Energy and Climate Change) EMR (Electricity Market Reform), with similar ideas gaining attention right across Europe. Capacity payments (paying plant not only for energy provided, but also for its capacity) are being regularly discussed as a potential solution to ensure investment.

Wholesale and retail prices likely to rise

The policies embarked upon by governments will put upward pressure on the cost of electricity to consumers and taxpayers. This stems fundamentally from the cost of building renewable generation: Low-carbon generation is more expensive than conventional thermal generation.

Low-carbon generation also needs support either via obligations on suppliers or subsidies in some

form. One option is to levy subsidies directly on end-users, leading to wholesale prices remaining low, but end-user prices rising substantially. A second possibility is to draw subsidies directly out of general taxation, keeping both wholesale and end-user electricity prices low, at the cost of higher taxes.

Another option could be the carbon price rises to act as incentive to low-carbon generation, perhaps to the extent envisaged by the UK government of £70/tonne by 2030. If there is only moderate reinforcement of interconnection, this is likely to cause both higher wholesale prices and divergence of prices between markets. This finding is in contradiction to the prevailing belief that European prices will harmonize into a *single price* as a result of increasing efforts to harmonize market designs.

A high carbon price highlights the difference in capacity mix between countries, with countries with large amounts of thermal generation having much higher wholesale prices than those that invest heavily in renewables (though not necessarily higher end-user prices).

Gas market knock-on effects

On windy days, all of the Combined Cycle Gas Turbine (CCGT) power plants on the system switch off. On still days all the capacity has to switch back on again. Gas demand volatility is likely to increase, which may require additional flexibility from gas infrastructure. This could come from new fast-cycle storage facilities, or it may more transparent and liquid traded markets could release underused storage resources across Europe.

The future outlined is not set in stone. A number of options could help mitigate the effects of intermittency across Europe but none of these offer a complete answer.

Greater interconnection

Benefits from interconnection occur by linking markets together, so the geographic area is bigger and hence the balancing of the wind is greater. The wider the geographic area, the lower is the correlation of wind. Hence the larger a market becomes, the less intermittent wind generation becomes. This is true to a point, as the output of wind farms in, say, Scotland alone is much more variable than wind farms in the whole of the UK. However, it is notable that periods of calm do extend to cover the entire North Europe region at the same time. We found wind generation across all of NW Europe together regularly drops below 5% of capacity.

Interconnection allows underused flexibility in one market to be moved to where it is needed. Hydro resource—particularly in Scandinavia—is often cited as the perfect counterbalance to wind generation. The stored energy in a reservoir can be held back and released in periods when there is little wind. The balancing that hydro provides significantly reduces price volatility and unpredictability, and in the work by Pöyry, the Nordic countries always have the lowest price volatility.

However, there is skepticism about Europe's ability to build interconnection between countries. It is costly, creates planning and environmental objections, and the benefits are asymmetric. Interconnecting Britain and Norway may bring cheaper electricity and flexibility, but will probably lead to higher electricity prices in Norway.

Electricity storage: shaky economics

The great hope for the future power system is electricity storage. The technologies on offer range through compressed-air energy storage, large-scale chemical batteries, flywheels, and supercapacitors. The value of electricity storage in a world of intermittency will rise. However, the business case for deployment of significant amounts of large-scale storage is hard to make.

First, the combination of high capital costs and efficiency means that price spreads need to be significant to make a commercial return. Second, such spreads are an ephemeral, risky source of revenues, so despite potentially high revenues if market prices are volatile, the risk of low volatility is too great to allow financing of projects.

Even storage built to provide ancillary services, unless there are long-term contracts in place, the commercial risk is too great. Without a radical change in cost or efficiency, financing and building large-scale energy storage is likely to remain uneconomic apart from niche applications. The exception is pumped hydro storage; in particular, where existing reservoir hydro can be re-powered, there is potential for competitive storage development.

Flexible demand and smart meters: complex and uncertain

The potential of the demand-side to play an active role in electricity markets has long been the hope of economists and engineers. Of the sources of flexibility available, demand-side has the greatest potential to transform, taking a potential highly intermittent, volatile, and risky world and helping to balance supply and demand and flatten prices.

Despite talk of intelligent fridges and washing machines, moveable demand in most homes is very small. The two big areas for demand side are heating and electric vehicles, both of which have substantial energy requirements and a good ability to store energy. But the cost of making these transformations is significant, often only achievable in new homes due to the costs of installation.

There is considerable work afoot to increase the amount of system flexibility by four other routes: interconnection, storage, demand side management, and flexible generation. But no one presents the single answer. The most likely scenario is a middle road of increased volatility, with some increase in various means of flexibility.

www.poyry.com

SPECIAL REPORT : WIND AND SOLAR POWER

Modeling and simulation for wind and solar energy

Computationally based design verification facilitates system optimization and testing in advance of hardware construction

By: Dr Peter van Duijsen, Technical Director, Simulation Research

The market for green and renewable energy is growing, but also presents numerous new challenges when it comes to technology, environment, and acceptance. Concerning technology, these challenges require not only new ideas, but also engineering effort to realize these new technologies. Reduction of cost and improving system efficiency are the two main engineering challenges.

The traditional build and test approaches are both time-consuming and expensive. Also, building and testing does not provide enough insight to reach an optimal design, not even thinking about the costs and construction time.

Use of engineering simulation software helps with the optimization of entire designs, whether it is a small-scale solar project or a large offshore wind park. Research for modeling and simulation in the field of green and renewable energy is a broad topic. Not only are the systems diverse, like wind and solar, but also the physical background of each type of green energy system varies greatly. For the modeling and simulation, this leads to two observations that design projects have to take into consideration:

1. Physical background of the underlying system
2. System or detail of the model of systems under investigation

First, for example, wind energy requires knowledge of electromagnetic energy conversion, while solar requires knowledge of semiconductor devices. Control in solar systems is mostly a sort of smart search algorithm that finds the optimum electric load for a solar module, while in wind power systems, the control is clearly dependent on the wind speed. Fuel cell, reformers, and batteries require knowledge of chemical processes. So, generally speaking, various technologies are used when working with green-energy systems.

Second the components can be modeled as simple system blocks with clearly defined functions but, on the other hand, multilevel models including all details can model them. For example, generator modeling in FEM and detailed semiconductor models in solar modules.

The first step is to get an overall picture of the power distribution in the system and to look at the load of every single system component. Typically, idealized system components are used. On this system level, an early concept of the control system can be designed and tested in simulation. For example, the MPP (maximum power point) control method can be tested together with the solar module, DC converter, and grid connection. Another example is the overall energy harvesting of a grid-connected wind turbine for varying wind speed.

The second step is to look at each component in more detail on the circuit level. One method is to replace the idealized system models with more detailed models. This increases overall simulation time, but gives more detailed simulation results. For example, a model including the semiconductor switches (IGBTs,

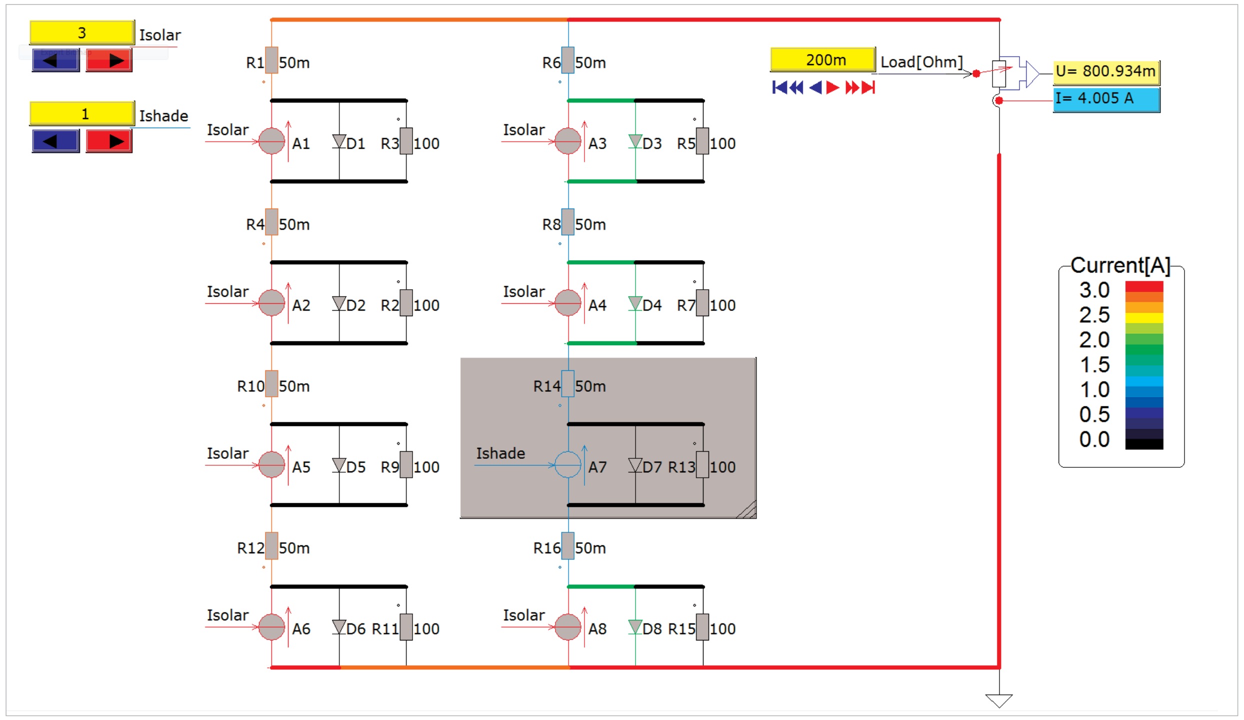


Figure 1: Shading and current distribution inside the solar module

MOSFETs, and diodes) could replace the ideal continuous model of a grid-connected inverter. The simulation results would now also include harmonics as well as typical modulation influences.

The third step would be to look at each component in more detail on the component level. Instead of using more detailed lumped circuit models with limited parameter sets from the second step, the models could be based on more detailed engineering software. For example, a non-linear model replaces the three-phase generator circuit model, where the input-output relations are pre calculated in FEM/BEM (finite- and boundary-element method) software.

Let's have a look at a number of typical simulation studies that give insight into the system. We start with a solar module containing a 4-x 3-cell array that, for some reason, is partly shaded. This is simulated on the second level (circuit level), since we want to know how the shading influences the behavior of the solar module (**Figure 1**). Here each solar cell is modeled using a sunlight dependent current source and a parallel diode and, yes, the diode is drawn in the correct direction. If the voltage across the solar cell gets beyond the typical on-state diode voltage of around 0.6 to 0.7 V, the diode starts conducting and short circuits the solar cell current.

In figure 1, color indicates the intensity of the current: red is maximum current and black is zero current. The shaded cell current is zero and this shaded cell blocks the current from the other cells that are in series with the shaded cell. Shading one cell means turning off a complete column in a module and therefore bypass diodes are included. However, bypass diodes also reduce the efficiency, while increasing the costs of the rotor module.

The second example shows the control of a grid-connected solar system. **Figure 2** shows the circuit model including the MPP control and grid-connection control.

A detailed second-level circuit model that includes load dependent loss and temperature dependency models the solar module. A boost converter that regulates the MPP for the solar module electrically loads the solar module. The boost converter is also modeled as

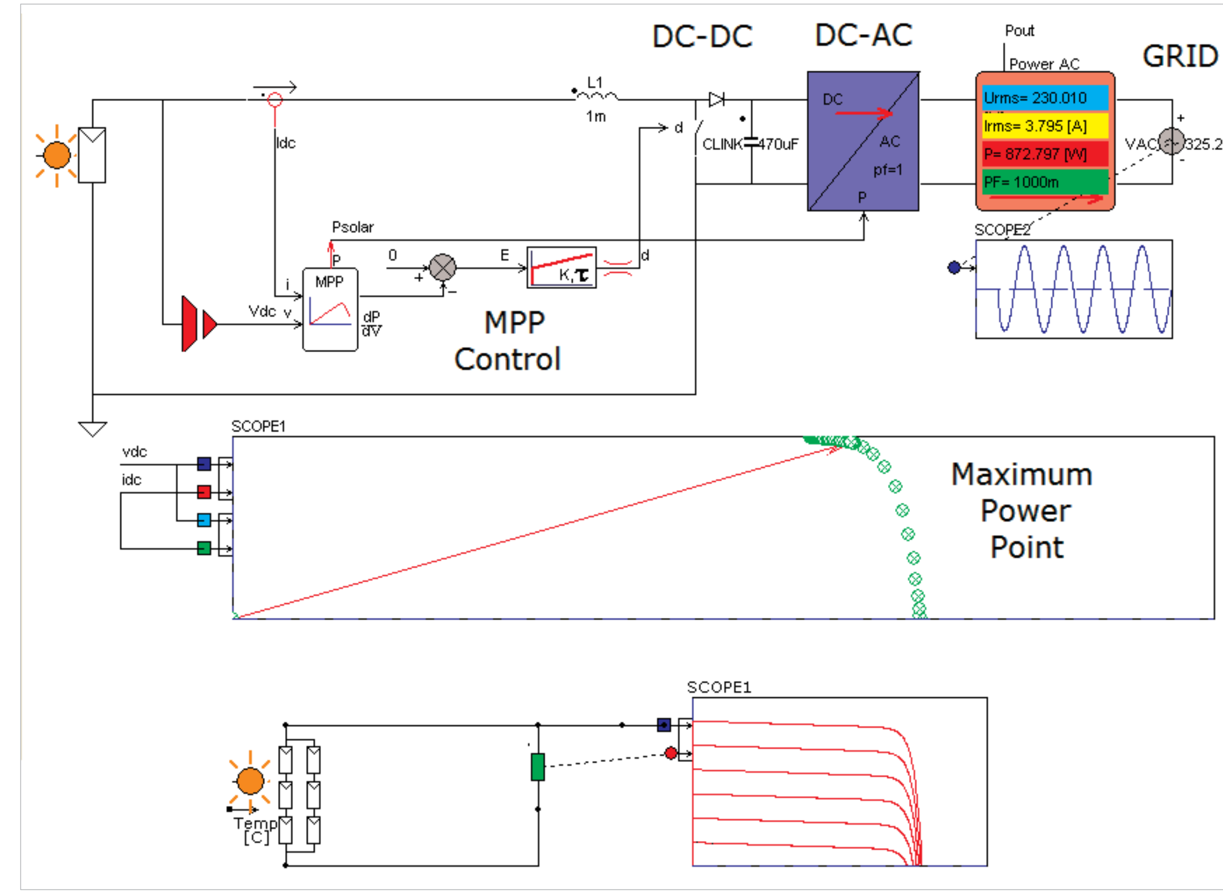


Figure 2: Grid-connected solar module with boost converter and MPP control

a second level circuit model. The MPP controller is a first level system model that calculates the derivative of the power as a function of the voltage of the solar module. Together with the first level system model for the PI controller, the amount of power harvested by the solar module is maximized. The last part is the grid connection. Here a first level system model for the inverter and control is used.

In the next example a more detailed model of a generator for a wind power system is examined. The efficiency of a wind power generator has to be optimized for two main reasons. First to maximize the amount of power the wind turbine generator can deliver and secondly to reduce the losses inside the generator. Each reduction of loss in the generator means that the generator delivers more output. Even 1% efficiency improvement is important when thinking about an average off-the-shelf 2 MW generator. An improvement of 1% means a reduction of 20 kW of loss that does not have to be cooled and 20 kW more that the system can deliver to the grid. Therefore,

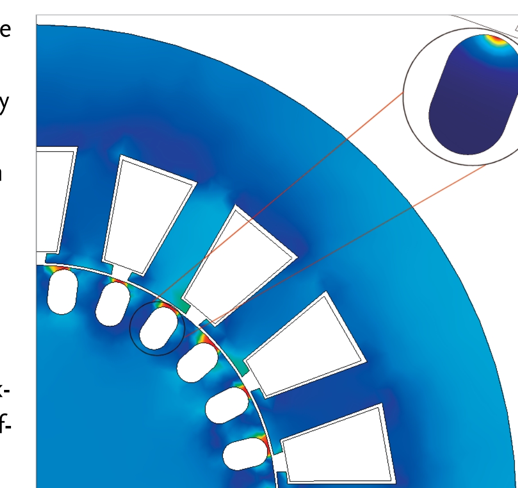


Figure 3: Field-magnitude plot in the rotor and stator of an induction motor; current density induced in one rotor bar (inset)

the bottom line in generator design is to optimize the generator

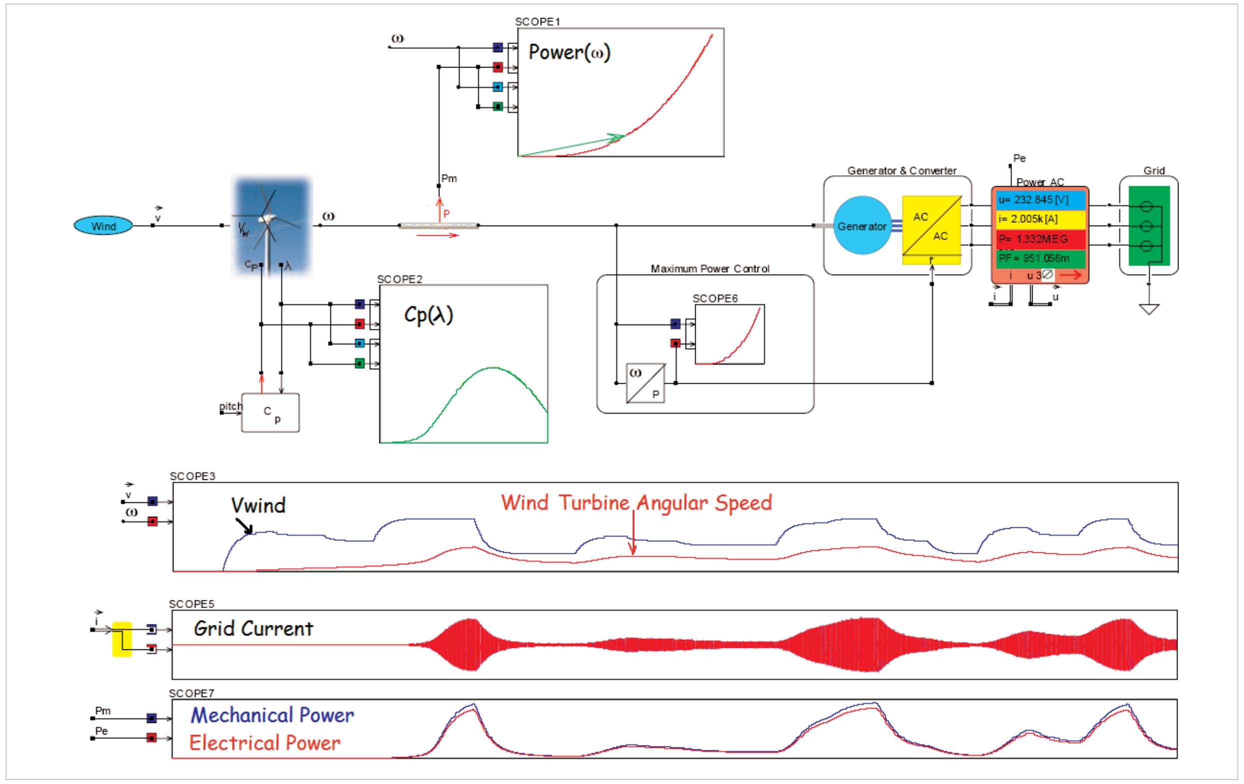


Figure 4: Wind turbine system with optimum power control

efficiency over a wide operating range.

Specialized FEM software that can model the generator in detail with manufacturer data for magnetic and ferromagnetic material is used here. Especially hybrid FEM/BEM solvers are in favor, since they do not require meshing of the airgap and therefore are more accurate than FEM-only solvers. From the hybrid simulation, look-up tables are generated that can be used in the system level or circuit level simulations. **Figure 3** shows the current distribution inside a rotor bar of an induction generator. Depending on the slip of the generator, the current distribution varies and, thereby, also the losses inside the rotor.

The concluding example shows an overall system simulation of a wind power system. A more detailed second-level circuit model can replace every single component in this first-level system simulation. Also third-level component models or even a mix between first-, second-, and third-level models would be possible in this type of simulation.

Figure 4 shows a grid connected wind turbine system with optimum power control. The maximum amount of power a wind turbine can deliver is equal to $k\omega^3$. Therefore, the control electrically loads the wind turbine generator such, that it subtracts exactly $k\omega^3$ Watts from the wind turbine and thus keep the system in equilibrium.

For varying wind speed, the control directly adjusts the amount of power drawn from the wind turbine generator and also controls the amount of power delivered into the main grid.

A second-level circuit model simulates the wind turbine, where the ratio between the wind tip speed and rotor angular speed determines the amount of power the wind turbine can deliver. This model is a minimum requirement when investigating the behavior for varying wind speed. The generator is modeled as a first-level system model, as the primary goal is to study the stability of the overall control system.

www.simulation-research.com

Solar and wind energy may stabilise the grid

Power grids with many small power plants could suffer fewer outages, but the new lines must be planned with care.

By: Dirk Witthaut and Marc Timme, Dynamics Group Researchers, Max Planck Institute for Dynamics and Self-Organization

Renewable energies such as wind, sun, and biogas are set to become increasingly important in generating electricity. If increasing numbers of wind turbines and photovoltaic systems feed electrical energy into the grid, it becomes denser—and more distributed. Therefore, instead of a small number of large power plants, it links a larger number of small, decentralized power plants with the washing machines, computers, and industrial machinery of power consumers.

Such a dense power grid however may not be as vulnerable to power outages as some experts fear. One might assume that it is much harder to synchronize the many generators and machines of consumers, that is, to align them into one shared grid frequency, just as a conductor guides the musicians of an orchestra into synchronous harmony.

In model simulations, scientists at the Max Planck Institute for Dynamics and Self-Organization in Göttingen have now discovered that consumers and decentralized generators may self-synchronise easily. Their results also indicate that a failure of an individual supply line in the decentralized grid is less likely to imply an outage in the network as a whole, and that while care must be taken when adding new links, paradoxically, additional links can reduce the transmission capacity of the network as a whole.

Synchronization, or the coordinated dynamics of many units to the same timing is found throughout the natural world. A similar form of harmony is also necessary in electricity networks, in that all generators and all machines that consume electricity must be tuned to the grid frequency of 50 Hz. The generators of large power plants are regulated in such a way that they stay in rhythm with the power grid. The grid, in turn, imposes its frequency on the washing machines, vacuum cleaners, and fridges at the other end of the line, so that all elements remain in synchrony, avoiding short circuits and emergency shutdowns.

In the course of the current energy turnaround, however, the structure of the power grid will change. Today's large power plants that supply energy to the surrounding areas will be largely replaced by multiple photovoltaic panels on roofs, biogas systems on fields, and wind turbines on hills and offshore. Power lines will no longer form star-like networks and only transmit energy from large power plants to nearby consumers, but will look more like dense fishing nets linking many generators with consumers.

Experts believe it will be very difficult to bring this multiplicity of small generators into synchronous harmony. In effect, it would be like conducting a huge orchestra with thousands of musicians, instead of a chamber orchestra. However, as the Network Dynamics Group, headed by Marc Timme at the Max Planck Institute for Dynamics and Self-Organisation in Göttingen has now discovered, synchronization in a decentralized power grid may actually be easier than previously thought, as a grid with many generators finding their own, shared rhythm of alternating current. In a decentralized grid, power plants and consumers synchronize themselves

The Göttingen-based scientists Dirk Witthaut and Marc Timme have simulated a dense network of small generators and consumers. Their computer model calculates the grid for an entire country—for practical reasons, they chose Great Britain—and takes into account the oscillations of all generators and electric motors that are connected to the grid. Combining this level of detail with this grid size is a new departure.

Previously, the dynamics of the oscillating 50 Hz AC current was basically only simulated for small networks. Simulations for larger grids did exist, but they were generally used only to make predictions regarding the static properties of the network, such as how much electricity would be transmitted from A to B. They completely ignored the oscillations of the generators and electric motors.

"Our model is sufficiently complex and extensive to simulate collective effects in complex networks and, just as importantly, it is simple enough that we can understand these effects too", says research project leader Dirk Witthaut.

The scientists simulated a very large number of networks, each with a different structure. The networks consisted of different mixes of large and small generators with lines of varying capacities, a little like country lanes and motorways for electrical current. This enabled them to identify differences between centralized and decentralized power grids.

Dense grid compensates more easily for line outage

The scientists in Göttingen examined additional aspects that are discussed in relation to the transition from a centralized grid to a decentralized one. What happens, for example, if a single transmission line is damaged or malfunctions? In existing grids, this can have a kind of domino effect, as seen in the 2006 power outage around Europe, caused by the shutting down of a single line in Northern Germany.

The simulations by the Göttingen-based team indicate that decentralized grids are much more robust when single lines are cut. This is because a dense grid has neighbouring lines that can take on the extra load of a downed line. In the case of large-meshed networks, they have few indispensable main links with the potential to cripple the whole grid.

But the expansion of renewable energy does hold challenges for the stability of the supply network. Simulation shows the scientists that a highly decentralized grid is more vulnerable to strong fluctuations in consumption, as occurs, for example, when millions of people turn on their washing machines at the same time. Large power plants can buffer these fluctuations in demand more easily than small ones, as their rotating generators store more kinetic energy. The grid can tap into these reserves at short notice to cover supply gaps—an option not available in the case of solar cells.

New lines can hinder power transmission

In a second study with the same mathematical model, Marc Timme and Dirk Witthaut discover another effect, known with road traffic, that is counterintuitive. Building a new road and increasing the network capacity does not necessarily improve traffic flow; on the contrary, even more congestion may occur with the same volume of traffic. This is when the new road provides a shortcut for many drivers, but has been poorly chosen in linking potential bottlenecks that were previously mostly avoided.

Braess's Paradox can be observed in power grids, specifically in decentralized networks. If such a dense network self-synchronizes, it might be assumed that synchronization would become easier with each new link; however, this is not always the case: the addition of a new line may actually disrupt self-synchronization.

In order to understand this paradox, consider two machines in a dense network. Additional machines are located along the line that connects them. The two machines are synchronous as long as the phases of their oscillations (oscillation at a given time and place) remain in a fixed, mathematically defined relationship to one another.

This may be visualized as two pendulums. The phase of the pendulum describes its degree of deflection at a given point in time. If the pendulums swing at the same frequency, their oscillations will be in a fixed phase relationship to one another. This does not mean that the two pendulums are swinging exactly parallel to each other, i.e. that they always have the same degree of deflection; in fact, they may even shift out of phase with each other. However, the distance between the swinging pendulums is fixed for every point in time, and the points at which they have the same degrees of deflection, recur at regular intervals.

Grid reaction to supply fluctuations

If two machines in a power grid are to be synchronized, that is, if their fixed phase relationship is to be fulfilled, they must always reach minimum and maximum voltage at the same time. This means that they must not be out of phase, or only by a full wave train. Every line in the network now yields a fixed phase relationship, either directly or indirectly. If a new line is now built to link the two machines directly, their oscillations must conform to a new phase relationship; however, this may not be compatible with the old one. Because the latter is consistent with the other machines on the old line, there is a conflict between the shortcut and the old line, which has the potential to desynchronize the entire network.

Careful consideration should be given to which nodes can be linked without risk. However, the results of the simulations are seen as encouraging for the construction of decentralized networks. "Until now, concerns rather centred on the possible collective impact that a large number of small generators could have in a dense grid", says the physicist. The fear was more frequent power outages. "But our work shows that the opposite is the case and that collective effects can be very useful."

The Network Dynamics Group based in Göttingen currently starts collaborating with engineers and network operators to ensure that their findings can be put to practical use. Initial contacts have already been made, and, in the meantime, the scientists are improving the model. Their current focus is to integrate weather-related fluctuations in renewable energy sources into their simulations.

www.mpibpc.mpg.de/81031/mpids

Five considerations for deploying Ethernet in wind farms

Maximize uptime and limit effects of single-point failures with robust network design for harsh wind-farm environments

By: Diane Davis, Director of Product Management, Ethernet Networking, Red Lion Controls

Data is a key element to the successful operation of a wind farm. Real-time data access allows operators to monitor wind turbine uptime, performance, and power output—even from remote locations. This data can track efficiency and trends, which are essential in the era of the Smart Grid.

But how can you capture this data under the rugged conditions of wind-farm environments? Industrial-grade Ethernet networks can seamlessly provide access to real-time data and maximize overall wind farm uptime.

First, it is important to note that conditions at wind farms are not suitable for traditional *commercial grade* communications and networking equipment. In fact, their conditions are far from normal. Extreme high and low temperatures, humidity, dust, vibration, and EMI from rotating generators and radio transmitters all make for a challenging environment in which to build an Ethernet network.

Maximizing uptime and preventing failures is important because wind farms are often built in remote areas where IT staff is not on site, so the labor expenses to fix technical issues (or to replace an entire switch) are even higher. Additionally, since the wind farm operator sells to consumers every kilowatt a wind generator produces, network downtime is very costly, so it is important to keep wind farms running as much as possible. As a result, wind farm operators need maximum uptime and high fault tolerance from their networks, and should use devices with high MTBF (mean time between failure) rates.

Industrial-grade Ethernet switches are specifically designed to operate in harsh conditions such as those described above, with high and low temperatures, dust, and vibration and wind farms are a classic example of an environment with these extreme conditions. Wind farms are often in areas where the weather can be very hot or very cold, and the wind turbines create vibration.

When selecting industrial Ethernet equipment and deploying it in a wind farm, it is important to consider the following five key characteristics:

Redundancy

Because you need to keep the network that supports the wind farms up and running at all times, redundancy is a key element in an industrial Ethernet switch. There are several ways to implement redundancy in these products. Since the power supply is one of the most common points of failure in any piece of electronics, be sure to look for an industrial Ethernet switch with redundant power supplies.

There are some key differences that should be noted within power supplies. While standard commercial-grade switches usually use low-cost, wall-mounted AC-DC power supplies that plug into standard wall receptacles, industrial Ethernet switches hardwire two redundantly independent power supply connections to the DC-power bus and backup power system. Industrial Ethernet switches also use dual-power inputs that accept AC, DC, or both voltage options, which helps protect against a single point of failure. This not only helps to protect wind farm networks from downtime caused by equipment failure, but also from lightning and voltage surges.

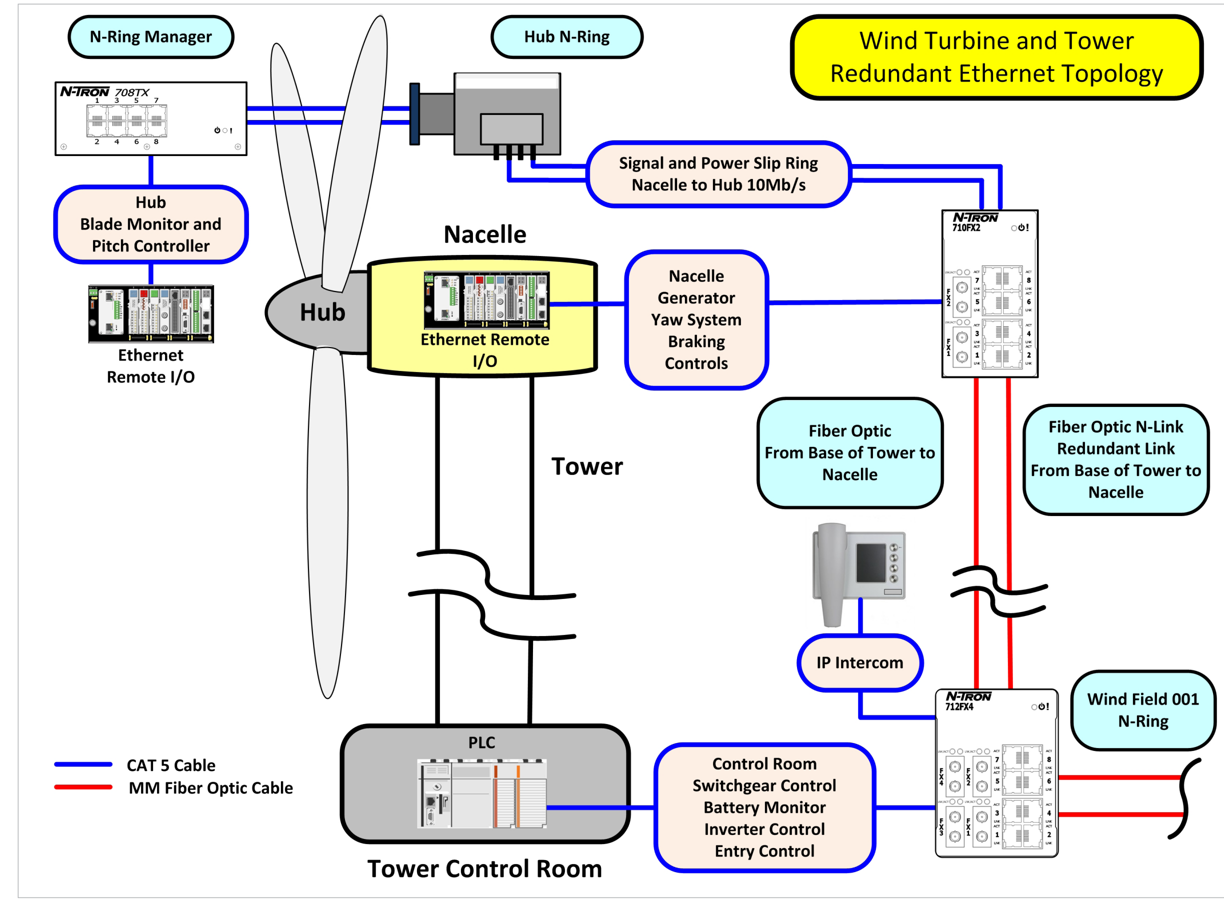


Figure 1: A network topology for wind-farm applications makes use of redundant devices and cabling to maximize system uptime and minimize the operational consequences of single points of failure.

Another issue that can cause network outages is cable breaks, which can be the result of human or natural causes, or connector or transceiver failures. To help prevent this, use a redundant *ring* configuration for cabling to help assure network uptime until an IT or maintenance crew can deploy on site to fix the issue.

Wind farms typically use a ring topology to connect turbines to a central location with fiber-optic cable. This configuration is superior because the ring lets the network re-route information if a failure occurs in one of its links. Wind farm operators might also use RSTP (rapid spanning tree protocol), a design that finds alternate and backup routes to redirect network traffic around failures in a mesh topology. The ideal network configuration supports both ring configurations and RSTP, and this would be the best option for a wind farm network.

Scalability

With global energy demand continuously increasing, many nations are turning to renewable energy sources like wind power. As demand continues to grow, the ability to scale up and expand will be essential.

Ring configurations have the flexibility to expand as wind farms grow, and support up to 50 industrial Ethernet switches per turbine, which provides significant scalability. Industrial Ethernet switches also offer a variety of port counts, depending on the number of devices that need to attach to the switch, so additional turbines can connect to the network as the wind farm grows.

Support for multiple types of fiber-optic cable

Fiber-optic cable is the ideal cable type to use in wind farms. It is important to note that there are two primary types of fiber cabling: MMF (multi-mode fiber) and SMF (single-mode fiber). MMF is appropriate for short to medium distances—up to 4 km—while SMF is suitable for longer distances, ranging from 20 to 60 km.

The industrial Ethernet switch should support both MMF and SMF, providing the maximum number of options to connect wind farms at different distances, depending on both immediate needs and how the wind farm expands over time. This will also help reduce costs by preventing you from having to buy different or additional switches to support one cable type versus another.

Temperature Rating

Power consumption directly relates to temperature ratings, which, in turn, can affect the reliability of a switch, making this a critical consideration when selecting an Ethernet switch. The temperature swings in wind farms—both hot and cold—can be extreme. The temperature range can be as low as €40 °C or as high as 75 ° C when there are no external cooling devices in place.

It is important to note that some manufacturers will build a standard grade product and then test the lot to find some units that work in extreme temperatures. In cases like this, the manufacturer did not specifically design and build the product to withstand extreme temperatures the way that manufacturers of industrial-grade Ethernet switches do. These standard products will often fail in the field, even though they tested successfully for a short time interval. For wind farms, it is vital to use only reputable, industrial-grade Ethernet switches that the manufacturer has designed, tested, and proven in the field to handle fluctuating temperatures and power consumption.

Management Protocols

Advanced management protocols, such as multicast and VLAN support, help to improve wind farm operation by providing real-time access to key network data that can be used to improve the efficiency of the network. Industrial Ethernet switches that deliver enterprise-class management features, combined with industrial-grade ruggedness, give a complete package that enables automated monitoring and management of network uptime, performance, traffic patterns and power output. As an added benefit, this monitoring and management can even be done from remote areas to avoid the high costs and resources that would otherwise be required to reach wind farms in distant locations.

www.redlion.net

Conference reflects broad scope of telecom-power field

By: David G. Morrison, Editor, How2Power.com

There was a time when the telecom-power industry largely focused on providing power equipment to support the delivery of POTS (plain old telephone service). That meant providing the AC-DC rectifiers and batteries required in the phone companies' central offices. However, as Kevin Parmenter (**figure 1**) discusses in his report on the recent INTELEC 2012 (International Telecommunications Energy Conference 2012) in Scottsdale, Arizona, the telecom industry has broadened dramatically over the years with the spread of wired and wireless voice, data, and video communications (**figure 2**). As a result, the telecom-power field has become broader as well.

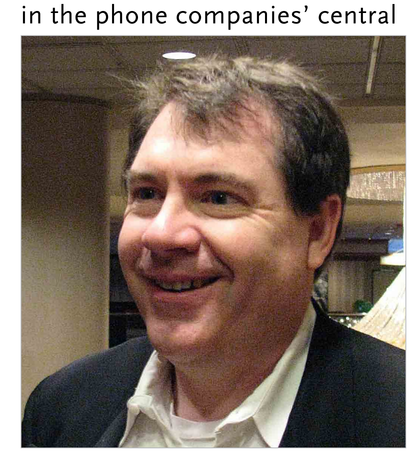


Figure 1: Kevin Parmenter

In *INTELEC bridges the telecom and energy worlds*, Parmenter describes the range of energy- and power-related technologies targeting today's telecom industry as reflected by the companies and individuals participating in INTELEC's exhibition and technical program. "The approximately 500 attendees present at this year's event represented a wide range of companies," writes Parmenter. Among these companies were providers of batteries and battery charging equipment, battery test and monitoring equipment, power systems, connectors, and high-current power-distribution products. Parmenter also noted the displays of fuel cells, generators, and hybrid power systems in the exhibition.

Figure 2: Power-system manufacturer Eltek's booth at INTELEC 2012 in Scottsdale, Arizona

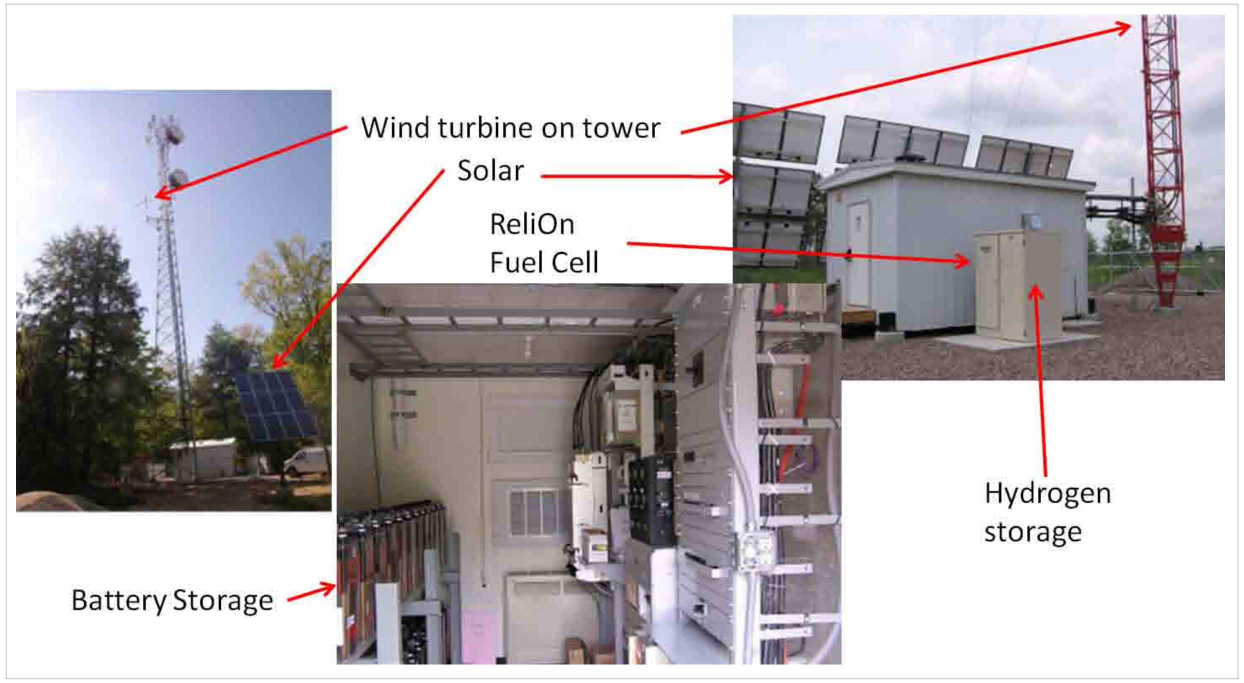


Figure 3: Switching from lead-acid to Li-ion batteries makes room for more telecom equipment in an off-grid hybrid site operating from batteries, wind, solar, and fuel-cell technology. (image courtesy A123 Systems)

Figure 4: GE Power Electronics offers innovative leasing and financing options as well as financial modeling to support power-system upgrades and improve energy efficiency.

Simply by reading this list of products, you may get a sense that the exhibit was heavily concerned with the issue of backup power. That was also Parmenter's observation.

As he writes, "This theme of backup power, which ran throughout the exhibit, reflects the reality that telecommunications systems, data-communications systems, and wireless are growing most rapidly in regions with no grid or an unreliable grid that can experience random and often sustained power outages. So to power these systems, sites must have multiple options, which can include solar, batteries, wind, fuel cells, grid-tied and generator-powered power sources. Moreover, the control systems and power electronics must be adept at switching seamlessly among these different power sources while managing the battery storage when power is available."

Among the offerings Parmenter observed at INTELEC was A123 Systems' Li-ion battery technology, which promises shorter charging times and more charging cycles without degradation (**figure 3**). He also reports on how GE Power Electronics is offering innovative leasing and financing options as well as financial modeling

"to support the [customer's] replacement of aging power systems with newer, more-efficient products"

(**figure 4**).

In addition, Parmenter writes about how trends in the telecom and energy worlds may lead to a convergence of these two fields. "The concern [among power-equipment suppliers] with the end customers' energy costs and their requirements for reliability suggests the need for interconnectivity between telecom systems and the power grid. With the emergence of the smart grid, it would seem that we're heading toward an interdependency between telecom systems, on the one hand, and the energy delivery systems (with their metering and intelligence) on the other," writes Parmenter.

Elaborating on this point, he continues, "One possible outcome is that the telecom system will be able to respond to changes in the grid preemptively and proactively in a seamless manner without human intervention. Conversely, if something needs attention at the remote telecom site, a service person will be alerted and simply show up with replacement parts before they are needed or if a redundant system has taken over."

Certain technologies such as intelligent battery-management systems, which are needed to support this vision of interconnected and interactive telecom systems and power grids, are already in place. However, as Parmenter explains in his report, a number of security issues will have to be addressed to support this convergence of telecom and power.

To read more of Parmenter's observations on INTELEC 2012 and trends in the telecom power field, see *INTELEC bridges the telecom and energy worlds* in the October 2012 issue of How2Power Today. This issue is available online at www.how2power.com/newsletters. Reading this article may inspire some readers, particularly those in Europe, to attend next year's INTELEC as it will be held October 13-17 in Hamburg, Germany.

About the author:
When not writing this column, David G. Morrison is busy building an exotic power electronics portal called How2Power.com. Do not visit this website if you're looking for the same old, same old. Do come here if you enjoy discovering free technical resources that may help you develop power systems, components, or tools. Also, do not visit How2Power.com if you fancy annoying pop-up ads or having to register to view all the good material. How2Power.com was designed with the engineer's convenience in mind, so it does not offer such features. For a quick musical tour of the website and its monthly newsletter, watch the videos at www.how2power.com and www.how2power.com/newsletters.

www.how2power.com

Unease over the thirteen European EASE creators

By: Gail Purvis, Europe Editor, Power Systems Design

Following on from a 2009 Energy Storage Task Force, a group of Europe's leading players in the energy sector—including manufacturers, utilities, and academic bodies—came together in Brussels in September 2011 to sign the formal constitution for the creation of EASE (the European Association for Storage of Energy). EASE was created to provide a single, coherent body of competence and influence to brings together the many diverse groups currently working in the energy-storage field. Its main aims are to stimulate the development of innovative energy storage technologies and applications through building a platform for the sharing and dissemination of knowledge and information, and to coordinate national activities. Consequently, EASE will act as a sound and visible advocate of energy storage in Europe.

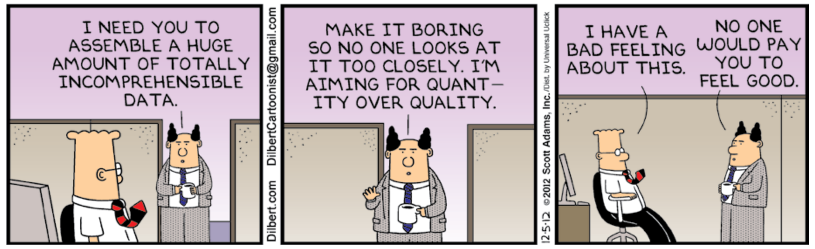
It is interesting to note however, that the thirteen founders are major power players Alstom, DONG Energy A/S, EDF SA, EnBW AG, Enel S.p.A., E.ON AG, GDF SUEZ SA, Hitachi Power Europe GmbH, KEMA BV, RISØ DTU, RWE AG, Saft SAS, Siemens AG. But curiously, that great chemicals giant, BASF (on record that batteries and fuel cells were chemical power plants) is not numbered among the early players. Neither, it appears, are the classic battery makers or fuel cell suppliers interested.

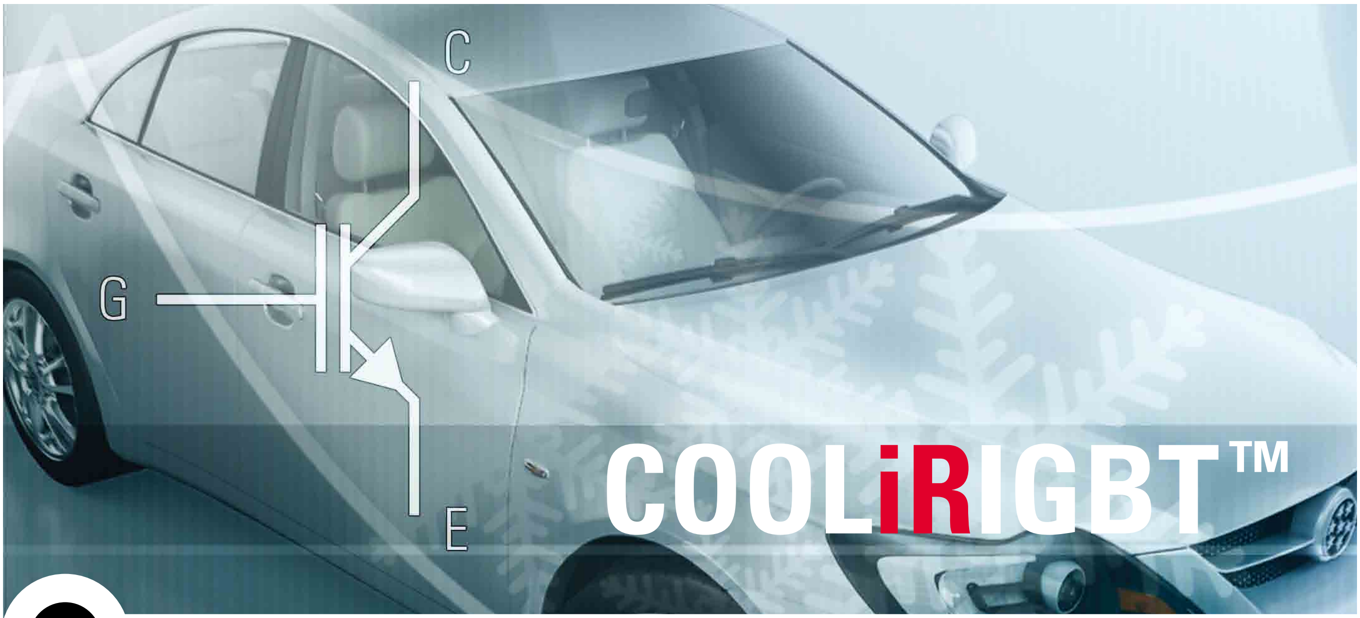
EASE designed as complementary to the existing EIIS (European industrial initiatives) in the framework of the SET (strategic energy technology) plan covering wind, solar energy, smart grids, green cars, smart cities, and efficient buildings as well as some PPPs (public-private partnerships). And EASE also cooperates with other national and international energy-storage organizations, having signed MoUs (memorandums of understanding) with Eurelectric and ESA (Electricity-Storage Association) in the US.

Its latest development is to have created its website (http://www.ease-storage.eu) while its Secretary General, Patrick Clerens (long-time secretary general for the European Power Plant Suppliers Association) is now looking actively for new members. It is to be hoped that the energy-storage field widens to include some long-term players and benefactors of the ability to store power.

In a world where energy-supply and –consumption patterns must change with large renewable energy sources and distributed generation, sustained increases in fossil fuel prices, changing market regulations, and stringent environmental targets, there is an enormous pressure to evolve to where effective energy storage can deliver strategic services to both regulated and deregulated power business, addressing the three major challenges: balancing demand and supply, management of transmission and distribution grids, and ultimately energy efficiency.

www.powersystemsdesign.com

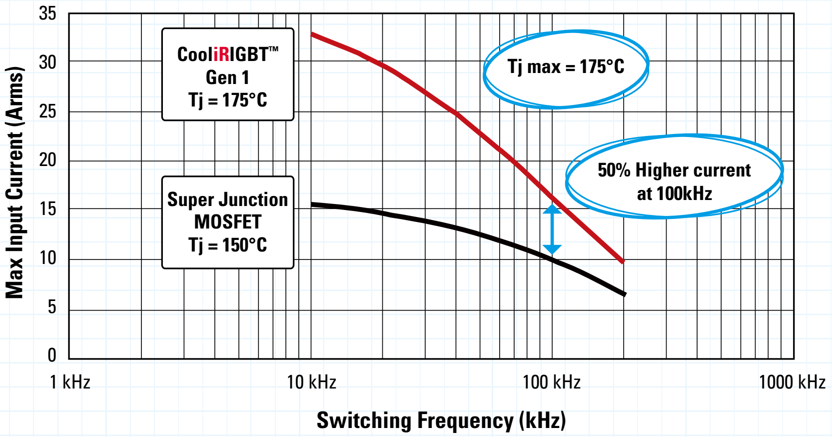




Automotive COOLiRIGBT™ Gen 1

Ultra-fast Switching, Rugged 600V High Frequency IGBTs

CooliRIGBT™ offers 50% higher current than super junction MOSFETs



	Super Junction MOSFET	COOLiRIGBT™ Gen1
Tj Max	150°C	175°C
Manufacturability	Complex	Simple
Switching Frequency	High	High
Losses At High Currents	High	Low

COOLiRIGBT™ Gen 1 are designed to be used in a wide range of fast switching applications for electric (EV) and hybrid electric vehicles (HEV) including on-board DC-DC converters, and battery chargers.

Features:

- Switching frequencies up to 200kHz
- 600V rated devices with a short circuit rating of > 5μs
- Low $V_{CE(on)}$
- Positive $V_{CE(on)}$ temperature coefficient making the parts suitable for paralleling
- Square Reverse Bias Safe Operating Area
- Automotive qualified
- Tj max of 175ºC
- Rugged performance
- Designed specifically for automotive applications and manufactured to the 0PPM initiative

For more information call +49 (0) 6102 884 311
or visit us at www.irf.com

International
IOR Rectifier
THE POWER MANAGEMENT LEADER